VOLUME II | TECHNICAL APPENDICES

PREPARED FOR

Massachusetts Port Authority

DRAFT ENVIRONMENTAL IMPACT REPORT/
ENVIRONMENTAL ASSESSMENT
EEA# 15665

Logan Airport Parking Project

Boston-Logan International Airport

EAST BOSTON, MASSACHUSETTS

PREPARED BY

vhb

IN ASSOCIATION WITH

WSP USA

Arrowstreet

MAY 2019

Appendices

- Appendix A, *MEPA Environmental Notification Form Certificate and Comment Letters*
- Appendix B, *Responses to Comments on the Environmental Notification Form*
- Appendix C, *Draft Section 61 Findings*
- Appendix D, *Federal Aviation Administration Terminal Area Forecast*
- Appendix E, *Surface Transportation Technical Appendix*
- Appendix F, *Air Quality/Emissions Reduction Technical Appendix*

This Page Intentionally Left Blank.

Appendix A

- MEPA Certificate on the Environmental Notification Form (ENF) and Comment Letters

This Page Intentionally Left Blank.

The Commonwealth of Massachusetts
Executive Office of Energy and Environmental Affairs
100 Cambridge Street, Suite 900
Boston, MA 02114

Charles D. Baker
GOVERNOR

Karyn E. Polito
LIEUTENANT GOVERNOR

Matthew A. Beaton
SECRETARY

Tel: (617) 626-1000
Fax: (617) 626-1081
http://www.mass.gov/eea

May 5, 2017

CERTIFICATE OF THE SECRETARY OF ENERGY AND ENVIRONMENTAL AFFAIRS
ON THE
ENVIRONMENTAL NOTIFICATION FORM

PROJECT NAME	: Logan Airport Parking Project
PROJECT MUNICIPALITY	: Boston
PROJECT WATERSHED	: Boston Harbor
EEA NUMBER	: 15665
PROJECT PROPONENT	: Massachusetts Port Authority (Massport)
DATE NOTICED IN MONITOR	: April 5, 2017

Pursuant to the Massachusetts Environmental Policy Act (MEPA; M.G. L. c. 30, ss. 61-62I) and Section 11.03 of the MEPA regulations (301 CMR 11.00), I have reviewed the Environmental Notification Form (ENF) and hereby determine that this project **requires** the preparation of a Mandatory Environmental Impact Report (EIR).

Project Description

As described in the ENF, the project includes the construction of 5,000 additional commercial parking spaces at the Logan International Airport (the "Airport"). The parking spaces will be located on additional floors within the existing Economy Garage and at a new parking garage in the location of the existing Terminal E surface parking lot. Potential phasing of the project and design of the parking structures is being developed; however, the ENF indicates that all 5,000 additional commercial parking spaces will be operational between 2022 and 2024. The ENF indicates that the parking spaces are intended to accommodate existing and anticipated air passenger demand for parking at the Airport. According to the ENF, the project will reduce drop-off/pick-up activity at the Airport and will reduce regional air passenger-related vehicle miles traveled (VMT) and associated air emissions.

In addition to the overall air quality benefits, the ENF indicates that Massport is considering additional high occupancy vehicle (HOV) mode improvement measures in conjunction with this project. These include enhancing Logan Express bus service through expanded parking at existing locations and increased frequency of service and expanding the Logan Express service area to new suburban locations and urban/downtown areas based on the success of the Back Bay Logan Express pilot program. The ENF also indicates that Massport is considering purchasing additional Silver Line buses to increase service capacity to the Airport.

Project Background and Context

The number of commercial and employee parking spaces allowed at Logan Airport is regulated by the Massachusetts Department of Environmental Protection (MassDEP) through the Massport/Logan Airport Parking Freeze (310 CMR 7.30), an element of the Massachusetts State Implementation Plan (SIP) under the federal Clean Air Act. The ENF indicates that peak day demand for on-Airport parking has been increasing, resulting in daily demand frequently nearing the Logan Airport Parking Freeze cap. Massport has filed this ENF concurrent with MassDEP's issuance of a draft regulation to amend the Parking Freeze. At Massport's request, the amendment would allow the creation of an additional 5,000 commercial parking spaces at the Airport. The MassDEP public comment period on the proposed regulations will close on May 8th, after this Certificate is issued.

As currently drafted, the regulations would increase the Logan Airport commercial parking freeze limit by 5,000 spaces (from 18,640 to 23,640 spaces) and would increase the total cap to 26,088 commercial and employee parking spaces (comprised of 23,640 commercial spaces and 2,448 employee parking spaces). The draft regulations include a requirement that Massport complete the following studies, each within 24 months of when the final regulations are promulgated, to identify ways to further support alternative transit options to the airport:

1. A study to evaluate the costs, feasibility, and effectiveness of potential measures to improve HOV access to the Airport. The study would consider, among other things, possible improvements to Logan Express bus service and the benefits of adding Silver Line buses with service to the Airport.
2. A study of costs and pricing for different modes of transportation to and from the Airport to identify a pricing structure and the use of revenues so generated to promote the use of HOV modes of transportation by Airport air travelers and visitors. The study will include evaluation of short-term and long-term parking rates and their influence on different modes of Airport transportation.
3. A study of the feasibility and effectiveness of potential operational measures to reduce non-high occupancy vehicle pick-up / drop-off modes of transportation to Logan Airport, including an evaluation of emerging ride-sharing and transportation network company modes.

This Project is contingent upon MassDEP amending the Logan Airport Parking Freeze regulation and EPA approval of an amendment to the SIP. If the regulations are not amended, the

Logan Airport Parking Project cannot proceed. The MassDEP regulatory amendment would provide the larger framework of the Logan Airport Parking Freeze, while project-specific impacts and mitigation measures will be analyzed through the MEPA review process for the Logan Airport Parking Project.

Logan Airport and Project Site

The Airport boundary encompasses approximately 2,400 acres in East Boston and Winthrop, including approximately 700 acres underwater in Boston Harbor. The airfield is comprised of six runways and approximately 15 miles of taxiway. Logan Airport has four passenger terminals, A, B, C, and E, each with its own ticketing, baggage claim, and ground transportation facilities. The Airport is surrounded on three sides by Boston Harbor and is accessible by two public transit lines and the roadway system. The preferred locations for the parking structures are the Economy Garage and the Terminal E surface parking lot. The Economy Garage is located in the northwest portion of the Airport campus at the intersection of Service Road and Prescott Street. It is comprised of two levels and provides over 2,700 spaces. The Terminal E surface parking lot is located within the Airport interior and adjacent to Terminal E.

As described in the ENF, the airport is well-served by public transportation and approximately 30% of travelers accessing the Airport arrive via HOV modes. Specifically, the Airport is served by several Massachusetts Bay Transportation Authority (MBTA) public transit routes, including Blue and Silver Lines for the rapid transit system, commuter ferry service, and local and express bus routes. Specifically, Massport provides free shuttle service between the Blue Line Airport Station and all Airport terminals and subsidizes the Silver Line Logan Airport Route (SL1) by providing free outbound Silver Line trips from the Airport on eight Silver Line buses purchased for this route by Massport. Massport also operates an extensive Logan Express Bus service, serving five locations. The airport is also served by other private express bus service and intercity bus service as part of the range of HOV modes available for ground access.

The Economy Garage and the Terminal E parking lot sites are both located within the coastal zone of Massachusetts. Both locations are comprised of previously disturbed impervious area. They are not located in Priority or Estimated Habitat as mapped by the Division of Fisheries and Wildlife's (DFW) Natural Heritage and Endangered Species Program (NHESP). The parking lot sites do not contain wetland resource areas regulated pursuant to the Wetland Protect Act and its implementing regulations (310 CMR 10.00).

Environmental Impacts and Mitigation

The project includes construction of 5,000 new commercial parking spaces at two locations. The project is located within previously altered impervious area and will not create new impervious area. According to the ENF, the new spaces are intended to accommodate existing and anticipated air passenger demand for parking at the Airport while minimizing pick-up and drop-off activity and decreasing regional air passenger-related VMT and associated vehicle emissions. Specifically, the ENF indicates that the project will reduce carbon dioxide (CO_2), volatile organic compounds (VOC), and oxides of nitrogen (NO_x) emissions by approximately 25% in 2022 and approximately 20% in 2030 as compared to the future No-Build Alternative.

The ENF indicates that expanded overall HOV capacity will be necessary to maintain the current HOV mode share as total passenger trips increase. In addition to the overall project benefits and HOV related measures proposed as part of the amendment to the Logan Parking Freeze, the ENF indicates that Massport is considering undertaking additional HOV measures in conjunction with the construction of the proposed 5,000 parking spaces. These include: enhancing existing Logan Express scheduled bus service; expanding Logan Express scheduled bus service; exploring Logan Express scheduled bus service in the urban/downtown area; and investing in additional MBTA Silver Line buses. In addition, the parking garages may be designed to be certified in the new "Parksmart" program, which applies Leadership in Energy and Environmental Design (LEED) sustainability strategies to structured parking facilities. The ENF indicates that measures to avoid, minimize, and mitigate project impacts will be further defined in the DEIR.

Jurisdiction and Permitting

The project is undergoing MEPA review and requires preparation of a mandatory EIR pursuant to 301 CMR 11.03(6)(a)(7) because it will be undertaken by a State Agency and will construct greater than 1,000 parking spaces in a single location.

The project may require a Sewer Permit Modification from the Boston Water and Sewer Commission (BWSC). The project may be subject to Massachusetts Office of Coastal Zone Management (CZM) federal consistency review. As indicated above, this project is contingent upon MassDEP amending the Logan Airport Parking Freeze to allow the creation of an additional 5,000 commercial parking spaces at the Airport. Should the draft regulations which propose amending the freeze be promulgated as final, MassDEP will submit the final amended Parking Freeze regulations to the U.S. Environmental Protection Agency (EPA) for approval and incorporation into the SIP.

The project may require approval by the Federal Aviation Administration (FAA), which would trigger review under the National Environmental Policy Act (NEPA).[1] The project also requires a National Pollutant Discharge Elimination System (NPDES) General Permit for Construction from the EPA.

Because the project will be undertaken by a State Agency, MEPA jurisdiction is broad in scope and extends to all aspects of the project that may cause Damage to the Environment, as defined in the MEPA regulations.

[1] The ENF indicates that the level of NEPA review, if required, will depend on the chosen alternative and will be at the discretion of the FAA.

Review of the ENF

The ENF includes a general description of proposed activities, a conceptual discussion of proposed conditions, a brief analysis of alternative locations, and an executive summary of the project in English and in Spanish. The ENF provides a suggested scope for the DEIR that identifies further analysis and data that will be provided to assess potential impacts and measures to avoid, minimize, and mitigate these impacts. The ENF does not provide project plans nor a description of the parking structures and notes that design of the structures is pending MassDEP amending the Parking Freeze. I expect that the DEIR will be a comprehensive and thorough filing that includes project plans for the Preferred Alternative and demonstrates that impacts have been avoided, minimized, and mitigated to the maximum extent feasible. C.1

Comments

MassDEP comments indicate that the draft Parking Freeze Amendment is under review and public comment is ongoing. Their comments identify design recommendations for the parking structures (including installation of electric vehicle (EV) charging stations and designation of preferred parking spaces for alternative fuel vehicles) request Massport implement measures to increase HOV and transit travel modes to the airport, including those identified by Massport in the ENF and providing incentives to increase HOV use.

Comments from industry and labor groups support the project and identify the economic support that the Airport provides to the region, including jobs, tax revenue, and financing for business growth. Other comments emphasize the importance of Massport implementing additional measures to reduce reliance on single occupancy vehicles (SOV), including those identified by Massport in the ENF. In addition, comments request Massport consider: implementing a toll for vehicles entering or exiting the airport to be used for HOV improvement measures, improving silver line (SL1) service (in addition to adding new vehicles), and improving the shuttle connection between the Blue Line and the terminals. The Scope for the DEIR requires additional information regarding project mitigation measures and methods to sustain and increase HOV mode share. C.2

Alternatives Analysis

The ENF indicates that the planning process considered six alternative on-airport locations for the structured parking facilities. All of the sites are paved and developed areas that are currently used for parking or vehicle storage. The ENF indicates that each of the sites are comparable in terms of regional VMT and emissions reductions since regional access routes will not vary as a result of the garage siting.

- Harborside Drive – Structured parking in location of existing vehicle layover space
- Porter Street – Structured parking over existing taxi pool
- North Cargo Area – Expand Economy Garage in the location of existing surface parking and the Massachusetts State Police building
- Southwest Service Area – Structured parking in location of current bus/limousine pool and overflow parking

- Economy Garage (Preferred Alternative) – Additional spaces above existing garage
- Terminal E Surface Lot (Preferred Alternative) – Structured parking in location of existing surface parking lot

According to the ENF, the Preferred Alternative was selected based on input from the East Boston Logan Impact Advisory Group (LIAG). The ENF indicates that Harborside Drive and Porter Street sites were eliminated due to potential wayfinding and operational challenges and the North Cargo Area was eliminated due to the need to relocate the existing uses. The Southwest Service Area was eliminated as it would require construction of a new parking structure and integration of existing uses into the ground floor. The ENF indicates that the No-Build alternative was eliminated as it would result in higher pollutant emissions and roadway congestion due to the higher VMT associated with the drop-off/pick-up mode. The ENF identifies the Economy Garage and Terminal E Surface Lots as the Preferred Alternative. The ENF indicates the Economy Garage location was selected as the Preferred Alternative because the site access is well defined, it does not require significant changes to existing roadway infrastructure, and it is adjacent to compatible land uses and the Terminal E Surface Lot location was selected due to its proximity to Airport terminals, compatibility with adjacent land uses, and location within the Airport interior to minimize impacts to adjacent communities.

Air Quality

The project is anticipated to shift mode share from drop-off/pick-up modes and result in reductions in regional off-Airport VMT compared to the future No-Build scenario. The project will result in CO_2, VOC, and NO_x reductions of 25.8%, 25.5% and 25.6% (respectively) in 2022 and 20.2%, 20.0%, and 20.2% (respectively) in 2030 as compared to the future No-Build scenario.

The analysis assumes that HOV modes can accommodate the proportional growth in passenger levels. The ENF indicates that Massport will continue to strive to maintain the current HOV mode share levels, and expand overall HOV capacity as total passenger trips increase.

The ENF indicates that an updated air quality analysis will be provided in the DEIR.

GHG Emissions and Sustainability

The project is subject to review under the May 5, 2010 MEPA Greenhouse Gas Emissions Policy and Protocol ("the Policy"). The ENF indicates that Massport will quantify stationary and mobile source emissions (passenger vehicles) generated by the project. Massport has indicated that stationary source emissions will only be evaluated if the garage contains conditioned spaces. I refer Massport to DOER's comment letter which identifies a limited number of GHG measures that should be evaluated regardless of whether the garages include conditioned space.

The ENF identified Massport's efforts to maintain and increase HOV modes, including strategies related to pricing (incentives and disincentives), service availability, service quality, marketing, and traveler information. The ENF indicates that the parking garages may be designed to be certified in the new "Parksmart" program, which applies LEED sustainability strategies to structured parking facilities.

Noise

The ENF indicates that ground noise impacts will not change significantly as the project will not require proposed relocation of or changes to existing land use. The ENF indicates that the proposed vertical addition to the Economy Garage may act as an additional noise barrier to the adjacent neighborhood.

Construction Period Impacts

The ENF indicates that construction period impacts and associated mitigation measures, including noise, air quality, traffic, solid and hazardous waste, and water quality will be evaluated in the DEIR. It will also describe project phasing and sequencing. Massport participates in MassDEP's Clean Construction Equipment Initiative and requires engine retrofits to reduce exposure to diesel exhaust fumes and particulate emissions. The ENF indicates that construction activities will comply with MassDEP Solid Waste and Air Quality control regulations.

SCOPE

General

The ENF included a proposed scope for the DEIR. It includes an executive summary, project description, alternatives analysis, planning and sustainable design, traffic and multi-modal transportation, air quality and GHG, and construction impacts. In addition to the Scope items proposed in the ENF, the Scope for the DEIR should be supplemented by the additions and modifications identified below.

Project Description and Permitting

The DEIR should include site plans for existing and post-development conditions at a C.3
legible scale including the proposed garage structures and any curbside improvements and
changes to the on-airport roadways. The DEIR should provide additional information to address C.4
construction sequencing and phasing. The DEIR should address traffic volumes and crash rates
at the Airport. It should include a description of existing and proposed conditions, including on C.5
and off-Airport access, on-Airport circulation, and parking. The project description should
address pedestrian and transit connections between the garages and the airport; pedestrian, C.6
transit, and vehicular access and egress locations; access and revenue control systems;
anticipated rate structures; and identify hybrid, alternative fuel, and EV parking locations. As
requested by MassDEP, it should include an evaluation of incorporating EV charging stations C.7
into the parking garages and identify the number and location of proposed stations. It should

include a discussion of how the construction and design of the garage could facilitate future expansion of EV charging stations if warranted by demand. C.7 Cont.

As indicated above, the draft amended Parking Freeze regulations would require Massport to complete three studies to identify ways to further support alternative transit options to the Airport. The results of these studies can be used to inform and benefit the development of mitigation measures for the Logan Airport Parking Project. The DEIR should clarify the timeframe for completed studies relative to the timeframe for developing specific mitigation measures for the Logan Airport Parking Project which are identified in the ENF. It should identify any commitments that would be contingent on the completion of a study. C.8

The DEIR should address ground access considerations associated with the parking structures. C.9 It should describe site and design constraints for both locations. It should identify how the Terminal E garage will be designed consistent with the curbside improvements and changes to on-airport runways associated with the Terminal E Modernization Project which will commence construction in 2018. C.10 The DEIR should identify and describe any changes to the project since the filing of the ENF and provide an update on permitting. It should include a discussion of permitting requirements and document the project's consistency with regulatory standards, as appropriate. C.11

Alternatives Analysis

The DEIR should expand on the initial alternatives analysis and summarize the findings of and the input provided by the community process that guided site selection. The DEIR should identify the number of parking spaces that could be accommodated at each of the alternative locations and describe in more detail why the Southwest Service Area location was eliminated from consideration. C.12 The DEIR should evaluate potential construction phasing and configurations. C.13 It should compare and contrast benefits and potential impacts of alternatives in narrative form and in a tabular format. C.14 The ENF indicates that the project will provide sufficient parking to accommodate approximately five years of peak-day parking demand if growth trends continue at current rates. The DEIR should identify the planning metrics and analysis used to determine the final number of proposed parking spaces (5,000 spaces). C.15

Air Quality

As indicated above, the project is anticipated to shift mode share from drop-off/pick-up modes and result in reductions in regional off-Airport VMT compared to the future No-Build scenario. The project will result in CO_2, VOC, and NO_x reductions of 25.8%, 25.5% and 25.6% (respectively) in 2022 and 20.2%, 20.0%, and 20.2% (respectively) in 2030 as compared to the future No-Build scenario. As noted in the ENF, although there has been a long-term trend of decreasing emissions since 1990, airport-wide emissions of VOCs and NO_x are predicted to increase slightly from 2010 to 2030. The ENF indicates that a portion of this increase may be attributed to anticipated increases in air passenger activity levels and associated rise in regional and on-Airport VMT.

The air quality analysis provided in the ENF is predicated on maintaining an approximately 30% HOV mode share and proportional growth in demand for HOV. The DEIR C.16 should demonstrate that the HOV programs and any proposed HOV improvement measures will provide the capacity to meet demand associated with growth. Massport has made significant investments in programs to maintain and increase HOV modes and has been recognized as one of the top-ranking airports in terms of HOV/transit mode share. I note the 2015 Environmental Data Report (EDR) indicated that Massport's current ground access goal is to attain a 35.2% HOV mode share when annual air passenger levels reach 37.5 million. The ENF indicates that passenger levels are approaching this level with over 36 million passengers in 2016. To support Massport's investments and extend their benefits, the DEIR should include an evaluation of measures to support HOV use and extend the associated air quality benefits of the program and identify to what extent these measures will contribute towards attaining the future mode share goal.

These additional measures include: increasing the frequency of transit services, C.17 expansion of transit services, parking supply, and pricing; and implementation of tolls or charges that can be used to improve HOV measures. I note improvements to reduce idling time of HOV modes (i.e. Logan Express, Blue Line Airport Shuttle, and SL1 Silver Line) will also provide air quality benefits. I refer Massport to comment letters which recommend additional measures to improve HOV and reduce VMT. I note monitoring and reporting on the progress towards achieving the goals and success of the mitigation program can be addressed in the Long-Term Parking Management Plan and future Environmental Status and Planning Reports (ESPRs) and C.18 Environmental Data Reports (EDRs) (EEA#3247/5146).

The DEIR should identify and analyze localized on-Airport, community ground access, and air quality conditions at each of the proposed locations. The updated air quality analysis for existing and future year conditions should evaluate the changes in transportation and air quality C.19 emissions. The air quality analysis provided in the ENF should be revised to reflect the proposed construction phasing and timeframe to identify when the air quality benefits associated with reduced VMT will be realized.

<u>GHG Emissions and Sustainability</u>

The DEIR should include an analysis of GHG emissions and mitigation measures in accordance with the standard requirements of the MEPA GHG Policy and Protocol. The analysis C.20 should include project-related stationary source emissions (exterior/interior parking structure lighting, ventilation, etc.) and mobile source emissions (passenger vehicles). The DEIR should present an evaluation of mitigation measures as outlined in the comments from the Department of Energy Resources (DOER) as appropriate based on whether the parking structures will C.21 contain conditioned spaces. I note that DOER's comments also identify mitigation measures that should be explored absent conditioned space, including but not limited to reduced lighting power densities (LPD) for interior and exterior lighting, parking structure ventilation, and solar photovoltaic (PV) installations. At a minimum, I expect the DEIR will present an evaluation of C.22 the feasibility and impact of these measures. This evaluation can be performed as separate calculations in lieu of energy modeling.

The DEIR should include an evaluation of rooftop or carport solar PV. It should include a cost analysis to determine the financial feasibility of solar (including potential payback periods) and propose an installation that can be supported by the maximum available roof area (excluding areas dedicated for mechanical equipment) on both parking structures. The DEIR should include C.23 the assumed panel efficiency, estimate the electrical output of the system, and estimate annual GHG reductions due to the use of renewable energy instead of electricity or natural gas. The analysis should include a narrative and data to support the Proponent's adoption (or dismissal) of solar PV systems.

The GHG analysis should include an evaluation of the potential GHG emissions of the project's mobile emissions sources using the EPA MOVES emissions model. The DEIR should use data gathered as part of the air quality analysis to determine mobile emissions for Existing Conditions, and the future No-Build, Build, and Build with Mitigation Conditions. The Build C.24 with Mitigation Conditions should incorporate measures and associated reductions identified in the Air Quality section above that will support HOV use and extend the associated air quality benefits of the program.

The DEIR should provide emission tables that compare base case emissions in tons per year (tpy) with the Preferred Alternative showing the anticipated reduction in tpy and percentage C.25 by emissions source (direct, indirect and transportation). If the garages include conditioned space, information should be provided for each building in a format similar to the example table C.26 provided in DOER's comment letter.

The project is in the conceptual design stage and, as such, provides meaningful opportunities for incorporation of sustainability measures. The DEIR should describe the project's consistency with Massport's Floodproofing Design Guide to demonstrate that the project will incorporate measures into the structure and site design to address potential impacts C.27 related to predicted sea level rise.

Noise

The ENF indicates that constructing additional levels on the Economy Garage can serve as an additional noise barrier to the adjacent neighborhood. The DEIR should identify how the sound barrier benefits of the taller garage have been maximized through its design. This C.28 evaluation should account for the expanded Terminal E building.

Construction Period Impacts

The DEIR should identify construction period impacts, including noise, air quality, C.29 traffic, solid and hazardous waste, and water quality, and identify avoidance, minimization, and mitigation measures. The DEIR should describe the project phasing and sequencing and address C.30 how construction will occur to avoid impacting the existing constrained parking supply. It should address construction phasing and whether construction will occur simultaneously with the C.31 Terminal E project.

Mitigation and Draft Section 61 Findings

The DEIR should include a separate chapter summarizing proposed mitigation measures. This chapter should also include draft Section 61 Findings for each area of impact associated with Massport's Preferred Alternative. The DEIR should contain clear commitments to implement these mitigation measures, estimate the individual costs of each proposed measure, identify the parties responsible for implementation (either funding design and construction or performing actual construction), and a schedule for implementation. To ensure that all GHG emissions reduction measures adopted by the Proponent in the Preferred Alternative are actually constructed or performed by the Proponent, I require Proponents to provide a self-certification to the MEPA Office indicating that all of the required mitigation measures, or their equivalent, have been completed. The commitment to provide this self-certification in the manner outlined above should be incorporated into the draft Section 61 Findings included in the DEIR. C.32 C.33 C.34

Response to Comments

The DEIR should contain a copy of this Certificate and a copy of each comment letter received on the ENF. In order to ensure that the issues raised by commenters are addressed, the DEIR should include direct responses to these comments to the extent that they are within MEPA jurisdiction. This directive is not intended, and shall not be construed, to enlarge the scope of the EIR beyond what has been expressly identified in this Certificate. The response can refer to future EDRs and/or ESPRs to address issues that are not within the DEIR Scope. I recommend that Massport employ an indexed response to comments format, supplemented as appropriate with direct narrative response. C.35 C.36 C.37

Circulation

In accordance with Section 11.16 of the MEPA Regulations and as modified by this Certificate, Massport should circulate a hard copy of the DEIR to each State and City Agency from which the Proponent will seek permits. Massport must circulate a copy of the DEIR to all other parties that submitted individual written comments. Per 301 CMR 11.16(5), the Proponent may circulate copies of the DEIR to these other parties in CD-ROM format or by directing commenters to a project website address. However, Massport should make available a reasonable number of hard copies to accommodate those without convenient access to a computer and distribute these upon request on a first-come, first-served basis. Massport should send correspondence accompanying the CD-ROM or website address indicating that hard copies are available upon request, noting relevant comment deadlines, and appropriate addresses for submission of comments. A CD-ROM copy of the filing should also be provided to the MEPA Office. A copy of the EIR should be made available for review at the following Libraries: Boston Public Library – Main, Orient Heights, and East Boson Branches, Chelsea Public Library, Winthrop Public Library, and Revere Public Library. C.38 C.39 C.40 C.41 C.42

May 5, 2017
Date

Matthew A. Beaton

Comments received:

4/13/2017	Matthew Barison
4/14/2017	Massachusetts Competitive Partnership (MACP)
4/21/2017	Associated Industries of MA (AIM)
4/18/2017	South Shore Chamber of Commerce
4/21/2017	Association of Independent Colleges and Universities in Massachusetts (AICUM)
4/24/2017	Bill Schmidt, Vice Chairman, Winthrop Board of Health
4/21/2017	Boston Water and Sewer Commission (BWSC)
4/20/2017	Local 22 Construction & General Laborers' Union
4/25/2017	Patricia J. D'Amore
4/25/2017	John Vitagliano
4/25/2017	Frederick Salvucci
4/25/2017	Metropolitan Area Planning Council (MAPC)
4/25/2017	Massachusetts High Technology Council (MAHT)
4/25/2017	Wig Zamore (1 of 4)
4/25/2017	Wig Zamore (2 of 4)
4/25/2017	Wig Zamore (3 of 4)
4/25/2017	Wig Zamore (4 of 4)
4/27/2017	Boston Financial Services Leadership Council
4/27/2017	Department of Energy Resources (DOER)
5/5/2017	Massachusetts Department of Environmental Protection (MassDEP)

MAB/PRC/prc

Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection

One Winter Street Boston, MA 02108 • 617-292-5500

Charles D. Baker
Governor

Karyn E. Polito
Lieutenant Governor

Matthew A. Beaton
Secretary

Martin Suuberg
Commissioner

May 5, 2017

Matthew Beaton, Secretary
Executive Office of Energy and Environmental Affairs
100 Cambridge Street, Suite 900
Boston MA 02114

Re: EEA No. 15665 – Logan Airport Parking Project

Dear Secretary Beaton:

On April 5, 2017, the MEPA Office published notice of the Massachusetts Port Authority's (Massport) Environmental Notification Form (ENF) for the Logan Airport Parking Project (EEA No. 15665). Massport is proposing to construct 5,000 new commercial parking spaces at Logan Airport that are intended to accommodate existing and anticipated air passenger demand for parking while decreasing drop-off/pick-up vehicle trips to and from the airport, which in turn would reduce vehicle miles traveled and associated air emissions.

Before the Logan Airport Parking Project can proceed, the existing Massport/Logan Parking Freeze regulation at 310 CMR 7.30 must be amended to increase the commercial parking cap by 5,000 spaces as Massport has proposed. On March 24, 2017, the Massachusetts Department of Environmental Protection (MassDEP) issued proposed amendments to 310 CMR 7.30 for public comment that would allow 5,000 additional commercial parking spaces and require additional studies on ways to increase high occupancy vehicle (HOV) and transit travel to and from the airport. MassDEP held a public hearing on April 25, 2017, and is accepting public comments on the proposed amendments until May 8, 2017.

MassDEP will consider all public comments on the proposed amendments to 310 CMR 7.30 before promulgating final amendments. Since the MEPA comment period on Massport's ENF closes on May 5, 2017, MassDEP offers the following list of recommendations for future consideration based on the project as described in the ENF:

1. The installation of electric vehicle charging stations should be included in the parking garages for a minimum percentage of parking spaces and additional electrical wiring should be added to ensure additional spaces are “make ready” to accommodate additional electric vehicles as the percentage of vehicles in the fleets increases over time. The electrification of the transportation system is a key part of the Commonwealth’s plan to achieve greenhouse gas reduction goals under the Global Warming Solutions Act. **1-1**

2. The parking garages should include the designation of preferred parking spaces for battery electric vehicles, plug-in hybrid electric vehicles, and hydrogen fuel cell vehicles as an additional incentive to promote these vehicles. **1-2**

3. Massport should use construction equipment with engines manufactured to Tier 4 federal emission standards, which are the most stringent emission standards currently available for off-road engines. If a piece of equipment is not available in the Tier 4 configuration, then Massport should use construction equipment that has been retrofitted with the best available after-engine emission control technology, such as diesel oxidation catalysts (DOCs) or diesel particulate filters (DPFs), to reduce exhaust emissions during the construction period of the project. **1-3**

4. Massport should ensure that construction activities do not cause or contribute to a condition of air pollution due to dust, odor or noise pursuant to 310 CMR 7.09 *Dust, Odor, Construction, and Demolition,* and 310 CMR 7.10 *Noise*. **1-4**

5. Massport should identify plans to prohibit excessive idling during the construction period (e.g., driver training, periodic inspections by site supervisors, and posting signage) to ensure compliance with vehicle idling regulation (310 CMR 7.11) that prohibit motor vehicles from idling their engines more than five minutes unless the idling is necessary to service the vehicle or to operate engine-assisted power equipment. **1-5**

6. To sustain air quality benefits Massport should evaluate and implement measures to increase HOV and transit travel modes to the airport, including expanding Logan Express bus service, increasing Silver Line service to the airport, and providing incentives to increase HOV use. **1-6**

MassDEP anticipates providing more specific comments on the mandatory Environmental Impact Report (EIR) for the project consistent with information in the EIR and with final amendments to 310 CMR 7.30.

Sincerely,

Beth Card
Deputy Commissioner, Policy and Planning

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF
ENERGY AND ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENERGY RESOURCES
100 CAMBRIDGE ST., SUITE 1020
BOSTON, MA 02114
Telephone: 617-626-7300
Facsimile: 617-727-0030

Charles D. Baker
Governor

Karyn E. Polito
Lt. Governor

Matthew A. Beaton
Secretary

Judith F. Judson
Commissioner

27 April 2017

Matthew Beaton, Secretary
Executive Office of Energy & Environmental Affairs
100 Cambridge Street
Boston, Massachusetts 02114

Attn: MEPA Unit

RE: Logan Airport Parking Project, East Boston, EEA #15665

Cc: Arah Schuur, Director of Energy Efficiency Programs, Department of Energy Resources
Judith Judson, Commissioner, Department of Energy Resources

We've reviewed the Environmental Notification Form for the above-referenced project.

We understand that the proposed project consists of two parking structures at two locations. The project design is conceptual only and may or may not include enclosed, conditioned space. We note below analysis which would not be necessary to include in future submissions if the project does not include conditioned, enclosed space

Our detailed comments are as follows:

- Future submissions should demonstrate that the project is taking all feasible measures to avoid, minimize and mitigate GHG emissions. The GHG Policy and supporting documentation is available at http://www.mass.gov/eea/agencies/mepa/greenhouse-gas-emissions-policy-and-protocol-generic.html **2-1**

- Above-code mitigation measures and renewables should be thoroughly evaluated to maximize all feasible GHG avoidance, including: **2-2**
  - *PV*: Solar PV could have a significant positive effect on GHG reduction for this project.

- *Envelope:* We recommend at least two above-code envelope mitigation measures be evaluated. Be sure to consider the value of downsizing HVAC systems as envelope improves. *(Only include if conditioned space is proposed.)* **2-3**

- *Heat Pump:* Heat pumps may be an effective strategy, providing highly efficient cooling and heating while also enabling trading of concurrent heating and cooling. We recommend both space and water-heating heat pumps be evaluated. *(Only include if conditioned space is proposed.)* **2-4**

- *Variable Refrigerant Flow:* We recommend an evaluation of VRF, which also provide highly-efficient cooling and heating as well as trading of concurrent heating and cooling. *(Only include if conditioned space is proposed.)* **2-5**

- *Building/Garage Lighting:* We recommend a thorough examination of reduced lighting power densities for both interior and exterior lighting. **2-6**

- *Energy Recovery; High Efficiency Equipment:* Where not already required by code, we recommend energy recovery options be investigated. Above code heating, cooling, pumping, fan and appliances also typically provide effective GHG reduction approaches. *(Only include if conditioned space is proposed.)* **2-7**

- *Responsive Systems and Controls:* Responsive HVAC systems, where not already required by Code, such as economizers and demand controlled ventilation usually are effective GHG mitigation strategies which we recommend be investigated. *(Only include if conditioned space is proposed.)* **2-8**

- Extensive credits, incentives, and grants are available for efficiency measures and renewables, including:

  - Tax credits and accelerated depreciation for solar PV and solar thermal. (Logan may have to utilize a 3rd party vendor, who can take advantage of these benefits.)

  - Utility performance-based incentives for energy efficiency improvements

  - Grants for various technologies from the Massachusetts Clean Energy Center

  - Alternative energy credits (AECs) for renewable thermal production

We recommend a thorough evaluation be conducted on financial benefits associated with efficiency and renewables. **2-9**

Recommendations for Submission:

In order to expedite the DOER review, we recommend the following accompany the submission: **2-10**

- A table similar to the example below should be included. Table may be simplified to only lighting and ventilation if the project does not include conditioned space. **2-10 Cont.**

Measure/Area	Base Code 2013 90.1 App. G or 2015 IECC	Proposed	% Change	Comment
Roof Assembly U-value (Btu/hr-Ft^2-f)				
Bldg 1	*code value*	*design value*	%	
Bldg 2	*code value*	*design value*	%	
(Additional rows for each bldg.)	*code value*	*design value*	%	
Wall Assembly U-value (Btu/hr-Ft^2-f)				
Bldg 1	*code value*	*design value*	%	
Bldg 2	*code value*	*design value*	%	
Area Window/Area Wall (%)				
Bldg 1	*code value*	*design value*	%	
Bldg 2	*code value*	*design value*	%	
Window U-value (Btu/hr-Ft^2-f)				
Bldg 1	*code value*	*design value*	%	
Bldg 2	*code value*	*design value*	%	
AC Efficiency (EER)				
Bldg 1	*code value*	*design value*	%	
Bldg 2	*code value*	*design value*	%	
ERV Effectiveness (%)				
Bldg 1	*code value*	*design value*	%	
Bldg 2	*code value*	*design value*	%	
Boiler (% efficiency)				
Bldg 1	*code value*	*design value*	%	
Bldg 2	*code value*	*design value*	%	
LPD (Watts/sq ft)				
Bldg 1	*code value*	*design value*	%	
Bldg 2	*code value*	*design value*	%	
(continue to include service water, equipment, etc)				

- A description of the proposed building envelope assembly: report both component R-values and whole assembly U-factor. Utilize the pre-calculated relationships between R-Value and U-factor contained in Appendix A in the code. *(Only include if conditioned space is proposed.)* **2-11**

- A description of the building energy simulation model and procedures utilized. *(Only include if conditioned space is proposed.)* **2-12**

- A detailed and complete table of modeling inputs showing the item and the input value for both the base and as-designed scenarios. The area of the building should be included. *(Only include if conditioned space is proposed.)* **2-13**

- The output of the model showing the monthly and annual energy consumption, totalized and by major end use system. *(Only include if conditioned space is proposed.)* **2-14**

- Baseline (e.g. Code) energy use intensity and proposed mitigated building energy use intensity. *(Only include if conditioned space is proposed.)* **2-15**

- Project modeling files are to be submitted to the DOER with the submittal on a flash drive or may be transmitted via electronic file transfer to paul.ormond@massmail.state.ma.us. *(Only include if conditioned space is proposed.)* **2-16**

- Separate "side calcs" may be required for non-building energy consuming site improvements which are not included in the building energy modeling software (e.g. parking lot lighting). **2-17**

- Estimate area of roof potentially usable for solar development (e.g. 'Usable Roof Area" (URA)). Estimate resulting power production and associated GHG reduction if all this URA was utilized. **2-18**

- A description of the proposed project building usage and size, including a site plan and elevation views, should be included. **2-19**

- Provide a summary of discussions with MassSave. *(Only include if conditioned space is proposed.)* **2-20**

- We recommend cross-examining produced model results' total and individual end uses with representative, prototype buildings developed by Pacific Northwest National Labs/Department of Energy found here: *(Only include if conditioned space is proposed.)* **2-21**

    - https://www.energycodes.gov/sites/default/files/documents/BECP_901_2013_Progress_Indicator_0_0.pdf

    - http://www.energycodes.gov/sites/default/files/documents/2013EndUseTables.zip

    - https://www.energycodes.gov/commercial-energy-cost-savings-analysis

Sincerely,

Paul F. Ormond, P.E.
Energy Efficiency Engineer
Massachusetts Department of Energy Resources

MAPC
METROPOLITAN AREA PLANNING COUNCIL

SMART GROWTH AND REGIONAL COLLABORATION

April 25, 2017

Matthew A. Beaton, Secretary
Executive Office of Energy & Environmental Affairs
Attention: MEPA Office – Page Czepiga, MEPA #15665
100 Cambridge Street, Suite 900
Boston, MA 02114

RE: Logan Airport Parking Project, MEPA #15665

Dear Secretary Beaton:

The Metropolitan Area Planning Council (MAPC) regularly reviews proposals deemed to have regional impacts. The Council reviews proposed projects for consistency with *MetroFuture*, the regional policy plan for the Boston metropolitan area, the Commonwealth's Sustainable Development Principles, as well as impacts on the environment.

MAPC has a long-term interest in alleviating regional traffic and environmental impacts, consistent with the goals of *MetroFuture.* The Commonwealth also has established a mode shift goal of tripling the share of travel in Massachusetts by bicycling, transit and walking by 2030. Additionally, under the Global Warming Solutions Act (GWSA), the Commonwealth has a statutory obligation to reduce greenhouse gas emissions (GHG) by 25% from 1990 levels by 2020 and by 80% from 1990 levels by 2050.

In May 2016, the Massachusetts Supreme Judicial Court released a unanimous decision in *Kain vs. Massachusetts Department of Environmental Protection* ordering MassDEP to take additional measures to implement the 2008 Global Warming Solutions Act. Specifically, the Court held that MassDEP must impose volumetric limits on the aggregate greenhouse gas emissions from certain types of sources and that these limits must decline on an annual basis. This recent ruling reasserts the state's obligation to meet the goals laid out in the GWSA.

The Massachusetts Port Authority (Massport) has submitted an Environmental Notification Form (ENF) for the Logan Airport Parking Project (the Project). Specifically, the Project plans to construct additional parking by adding spaces atop the existing Economy Garage and above the existing Terminal E surface parking lot at Logan International Airport (Logan Airport). Potential phasing of the Project is still being developed, however Massport's goal is to have all 5,000 additional commercial parking spaces in service between 2022 and 2024. The ENF indicates the parking spaces are intended to accommodate existing and anticipated air passenger demand for parking at Logan Airport. According to the ENF, the Project will reduce drop-off/pick-up activity at the airport and will reduce regional air passenger-related Vehicle Miles Traveled (VMT) and associated vehicle air emissions.

Logan Airport has been subject to the Logan Airport Parking Freeze (310 CMR 7.30) on the number of commercial parking spaces there since 1975. In June 2016, Massport, the owner and operator of the airport, submitted a proposal to the Massachusetts Department of Environmental Protection (MassDEP) to amend the Logan Airport Parking Freeze by increasing the commercial parking freeze limit by 5,000 spaces, or 27 percent, from 18,640 to 23,640 spaces. The Project is contingent upon MassDEP amending the Logan Airport Parking Freeze. Massport has filed this ENF concurrent with MassDEP's issuance of a draft regulation to amend the Parking Freeze.

Metropolitan Area Planning Council | 60 Temple Place | Boston, Massachusetts 02111 | 617–933–0700 | 617–482–7185 fax | **mapc.org**

MAPC commends Massport for their past and ongoing work to advance transit access and high occupant vehicle (HOV) modes, as well as their continuing efforts to implement a comprehensive strategy to enhance ground transportation options for air passengers and employees to and from Logan Airport. Nevertheless, MAPC has concerns that the proposed increase in commercial parking spaces may inadvertently cause people who customarily use transit, shared-rides, and other HOV modes to access Logan Airport by single occupant vehicle (SOV) instead. **3-1**

Currently, the mode share of transit and HOV access to Logan Airport is about 30%, a percentage which has remained relatively constant since 2004. Having the unique advantage of being in close proximity to downtown Boston, Massport should look to continue serving as a model to other landowners and building operators by exploring ways to maximize the use of multimodal transportation options to the airport (e.g., Blue Line, Silver Line, water transport, Logan Express). It is paramount that Massport continue to support strategies to enhance transit, shared-rides and HOV as ways to reduce SOV trips. Simply allowing for an increase in parking spaces could have the inadvertent consequence of undermining these non-SOV alternatives. **3-2**

Following are MAPC's comments and concerns that address Massport's ENF, along with recommendations that would enhance transit, shared-ride, and HOV access to and from Logan Airport. We respectfully request that the Secretary require Massport to include the following when the Certificate is issued for preparation of the Environmental Impact Report (EIR) and for inclusion in the Section 61 findings.

<u>Proposed Studies</u>

MAPC applauds Massport for proposing to undertake three studies intended to aid their long-range efforts to address VMT and air quality impacts of different ground access modes for travel to and from Logan Airport, but we believe it is essential that Massport *first* conduct these studies and *then* implement their recommendations *before* increasing the number of commercial parking spaces. The three proposed studies are: **3-3**

1. *Ways to improve HOV access to the Airport*

Evaluate the feasibility and effectiveness of potential measures to improve HOV access to Logan Airport. The study would consider, among other things, possible improvements to Logan Express bus service, additional Logan Express sites, and the benefit of improvements to the Silver Line service to Logan Airport.

2. *Strategies for reducing drop-off/pick-up modes*

Evaluate the feasibility and effectiveness of potential operational measures to reduce drop-off/pick-up modes of access to Logan Airport.

3. *Parking pricing strategies*

Assess parking pricing strategies and their effect on customer behavior and VMT.

<u>Transportation Network Company (TNC) Trips</u>

Given Massport's concern regarding pick up and drop off activity and the resulting air quality degradation, MAPC is surprised that the ENF does not include any discussion of TNC trips (e.g., Uber, Lyft, Fasten), or any plan to analyze TNC trips in the EIR. The recent onset of TNC services is an unprecedented and rapidly growing transportation service likely to have significant impacts on airports. These services could potentially reduce the number of deadhead trips that are of most concern to Massport now that TNC's are allowed to pick up at Logan Airport as of February 1, 2017. For example, in the recently released report, *Unsustainable? The Growth of App-Based Ride Services and Traffic,* *Travel and the Future of New York City*[1] concluded that TNCs "have become an important and fast-growing part of the city's transportation system. In each of the last two years, they have been the leading source of growth in non-auto (i.e., non-personal car) travel in the city." *(p. 1)* In particular, this study confirms that the growth of TNCs is a significant component for travel to and from airports. According to the report, the amount of taxi and TNC trips accessing JFK and LaGuardia Airports has increased by 38% from 2013 to 2016[2]. This is higher than the overall 22% increase for the New York metropolitan area as a whole.

MAPC recognizes that due to their rapid growth and ready availability, app-based ride hailing options could present a challenge to airport ground operations. MAPC requests that Massport analyze, as part of the scope for the EIR, the extent to which TNC trips are impacting access to and from Logan Airport. **3-4** This study should also explore implementing a policy that requires taxis and TNCs not to deadhead when either arriving at or departing from Logan Airport. Requiring taxis and TNCs to carry air passengers both when entering and exiting Logan Airport could increase the efficient management of these trips, and negate all or part of the need for additional on-site parking. **3-5**

MAPC notes that, in a footnote, the ENF states that "[f]uture parking trends (such as transportation network companies [for example, Uber and Lyft], driverless cars, and reduced car ownership in urban areas) may impact demand further into the future; however, given the current understanding of these issues, they are not anticipated to impact the analysis presented in this ENF over the relatively near-term timeframe." *(p. 2-28)* MAPC, who has been closely following the rapidly evolving industries of TNCs and autonomous vehicles, respectfully disagrees with this assumption. In fact, we think it highly likely that TNCs are already having a sizeable impact on travel patterns, and they influence is almost certain to grow between now and the time the requested parking spaces are built. **3-6**

Pick-Up/Drop-Off Activity and Fee Structure

According to Massport, pick-up/drop-off vehicle activity is growing due to the constrained parking supply. As a result, this has led to an increase in the total number of vehicle trips generated by Logan Airport air passengers. Massport is concerned that if the commercial parking supply at the Airport remains the same, this will continue to cause an increase in both vehicle trips and curbside congestion due to pick-up/drop-off activity by private vehicles.

Our perspective is that the link between the lack of parking and pick-up/drop-off activity, while plausible, is not proven, and providing that proof should be a considerable objective of the EIR. **3-7**

One option to discourage drop-off and pick-up of air passengers is to consider implementing a drop-off/pick-up fee. Such a fee could improve air quality by reducing idling as well as encouraging the use of other modes of travel, such as public transit. For example, Dallas/Fort Worth International Airport charges a fee for both parking and pass-through activity. The airport's parking fee structure discourages air passenger pick-up/drop-off by charging $4 for 0-8 minutes and then drops the fee to $2 for 8-30 minutes[3]. At major airports in Great Britain, private vehicles must pay for the convenience of loading or unloading of passengers at airport entrances. MAPC requests that Massport prepare a study that evaluates the incorporation of fees for pick-up/drop-off activity. **3-8**

[1] Schaller Consulting, February 2017.
[2] Table 2. Combined Taxi/TNC trips, 2013 to 2016.
[3] Parking fees at Logan Airport increase incrementally over time.

First and foremost, Massport's ground transportation strategy needs to maximize the use of transit, shared-rides, and HOV modes of travel to and from Logan Airport. Respectfully, we believe it is essential that Massport *first* conduct these studies and *then* implement their recommendations *before* increasing the number of commercial parking spaces. The need for additional, robust measures is confirmed by Massport's own statement that the proposed parking increase will provide enough capacity to meet projected demand for less than 5 years[4]. Impacts at Logan Airport have a large impact on our regional transportation system and air quality and we therefore request that any modifications to the allocation of commercial parking spaces should not be permitted until all other options have been systematically and thoroughly evaluated and implemented.

Thank you for the opportunity to comment.

Sincerely,

Marc D. Draisen
Executive Director

cc: Thomas P. Glynn, CEO, Massport
Martin Suuberg, Commissioner, MassDEP
David Mohler, MassDOT

[4] ENF, Attachment 5, p. 5-44.

Boston Water and Sewer Commission

980 Harrison Avenue
Boston, MA 02119-2540
617-989-7000

RECEIVED
APR 25 2017
MEPA

April 21, 2017

Secretary Matthew Beaton
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Page Czepiga, EEA 15665
100 Cambridge Street, Suite 900
Boston, MA 02114

Re: Boston – Logan Airport
Parking Project
Environmental Notification Form

Dear Secretary Beaton:

The Boston Water and Sewer Commission (Commission) has reviewed the Environmental Notification Form (ENF) for the Boston Logan Airport, Parking Project. This letter provides the Commission's comments on the ENF.

The proposed project is located at Boston Logan Airport and consists of adding approximately 5,000 commercial parking spaces to be located at two sites on airport property. The sites are already paved and are currently used for parking or vehicle storage.

The water, sewer and storm drain system at Logan Airport is owned and maintained by Massport. The system is supplied by master water meters at the entrance to the airport and a sewer service connection at the entrance of the Airport.

The ENF states that the proposed project will not result in the use of additional water or generate additional wastewater that will impact the Commission's systems.

The Commission has the following comments regarding the ENF.

<u>Drainage</u>

1. As stated in the ENF, Massport will be required to prepare a Stormwater Pollution Prevention Plan. The plan must:

   - Identify specific best management measures for controlling erosion and preventing the discharge of sediment, contaminated stormwater or construction debris to the Commission's drainage system when construction is underway. **4-1**

- Include a site map which shows, at a minimum, existing drainage patterns and areas used for storage or treatment of contaminated soils, groundwater or stormwater, and the location of major control structures or treatment structures to be utilized during the construction.
- Specifically identify how the project will comply with the Department of Environmental Protection's Performance Standards for Stormwater Management both during construction and after construction is complete.

4-1 Cont.

2. As stated in the ENF, the project will be required to obtain an NPDES General Permit for Construction from the Environmental Protection Agency and the Massachusetts Department of Environmental Protection because the project will disturb more than one acre of land. It is required that a copy of the permit and any pollution prevention plan prepared pursuant to the permit be provided to the Commission's Engineering Services Department, prior to the commencement of construction. The pollution prevention plan submitted pursuant to a NPDES Permit may be submitted in place of the pollution prevention plan required by the Commission provided the Plan addresses the same components identified in item 1 above. **4-2**

3. As stated in the ENF, Massport develops dewatering and discharge plans for all construction plans at Logan Airport. If required, groundwater treatment and discharge construction practices will be defined and submitted to MassDEP for approval. The discharge of dewatering drainage to a sanitary sewer is prohibited by the Commission. Massport is advised that the discharge of any dewatering drainage to the storm drainage system requires a Drainage Discharge Permit from the Commission. If the dewatering drainage is contaminated with petroleum products, the proponent will be required to obtain a Remediation General Permit from the Environmental Protection Agency (EPA) for the discharge. **4-3**

4. The Commission requests that Massport install a permanent casting stating "Don't Dump: Drains to Boston Harbor" next to any catch basin created or modified as part of this project. Massport should contact the Commission's Operations Division for information regarding the purchase of the castings. **4-4**

5. The enclosed floors of a parking garage must drain through oil separators into the sewer system in accordance with the Commission's Sewer Use Regulations. The Commission's Requirements for Site Plans, available by contacting the Engineering Services Department, include requirements for separators. **4-5**

Thank you for the opportunity to comment on this project.

Yours truly,

John P. Sullivan, P.E.
Chief Engineer

JPS/cj

c: S. Dalzell, Massport
K. Pedersen, BRA
M. Zlody, BED
P. Larocque, BWSC

BILL SCHMIDT
32 BUCHANAN STREET
WINTHROP, MA 02152

RECEIVED
APR 24 2017
MEPA

April 24, 2017

The Honorable Matthew Beaton
Secretary of Energy and Environmental Affairs
Attention: MEPA Office
Page Czepiga, EEA #15665
100 Cambridge Street, Suite 900
Boston, MA 02114

Re: ENF for Logan Airport Parking Project

Dear Secretary Beaton:

As the Vice Chairman of the Winthrop Board of Health, I am pleased to have the opportunity to submit comments on the Environmental Notification Form for the Logan Airport Parking Project.

As I stated in my January 20, 2017 letter to you on the Boston-Logan International Airport 2015 EDR, I have concerns about the Logan Airport Parking Proposal to build up to 5,000 new on-airport commercial parking spaces and its effects on the environment and the Winthrop community. This may affect the efforts to increase the use of High Occupancy Vehicles (HOVs), transit, and shared-ride options for travel to and from the airport and to minimize vehicle trips. **5-1**

Rather than amending the existing Logan Airport Parking Freeze Regulation (310 CMR 7.30) to allow for 5,000 more on-airport parking spaces, a lower amount combined with other measures should be implemented to reduce local and regional vehicle miles traveled (VMT) and vehicle air emissions associated with greater access to Boston-Logan International Airport. **5-2**

Efforts should be made to convert significant additional on-airport employee spaces to in-service commercial spaces, **5-3** and consideration should be given to methods to reduce the amount of commercial parking for periods greater than 4 days by large increased rates for these days, which should increase turnover. **5-4**

Instead of building new parking garage facilities at both the Economy Garage (Site 1) and the Terminal E Surface Lot (Site 2), building at the Terminal E Surface Lot alone could accommodate 3,000 spaces and its proximity to the Airport terminals provides an opportunity for parkers to walk to their respective terminals, reducing the need for operational resources (such as shuttle bus service) and reducing resultant on-Airport VMT. **5-5**

In addition, Massport should make it a priority to convert the remaining 702 Park and Fly spaces in the East Boston Freeze Cap to commercial spaces at Logan Airport. **5-6**

Massport has proposed several broad mitigation commitments to MassDEP associated with their proposed Parking Freeze amendment. Massport has proposed three long-term studies: Ways to improve HOV access to the Airport; Strategies for reducing drop-off/pick-up modes; and Parking pricing strategies. These should be completed at the earliest possible date. **5-7**

I appreciate the MEPA office's consideration of these concerns and look forward to your efforts to address them.

Sincerely,

Bill Schmidt
Vice Chair, Winthrop Board of Health

cc: Stewart Dalzell, Massport
Speaker Robert DeLeo
Senator Joseph Boncore
James McKenna, Town Manager
Robert Driscoll, Council President
Richard Boyajian, Councilor at Large
Nick LoConte, Board of Health
Susan Maguire, Board of Health
Richard Bangs, WAPNAHC
Jerome Falbo, WAPNAHC
John Vitagliano, WAPNAHC

AICUM

Association of Independent Colleges and Universities in Massachusetts

11 Beacon Street, Suite 1224 | Boston, Massachusetts 02108-3093
617.742.5147 | FAX 617.742.3089 | www.masscolleges.org

April 21, 2017

Matthew Beaton
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Page Czepiga, EEA No. 15665
100 Cambridge Street, Suite 900
Boston MA 02114

Dear Secretary Beaton:

On behalf of the Association of Independent Colleges and Universities in Massachusetts, I am writing to express support for Massport's request to amend the Logan Airport Parking Freeze to add up to 5,000 new parking spaces at the airport. The current situation – where the ability to park at the airport is so uncertain – results in poor customer experience, lost time, potentially missed flights as well as a decrease in air quality. Logan Airport is an essential economic engine for the region, and it needs the capacity in its facilities to meet its customers' needs as efficiently as possible with minimal impact on the environment and the surrounding neighborhoods. **6-1**

It is our understanding that Logan Airport is the only airport in the United States that operates under a parking freeze. The original goal of the freeze to reduce Carbon Monoxide (CO) emissions was an important one. After decades of technological improvement and changes in consumer behavior, emissions overall are down. It appears that raising the cap on the freeze at this time would *reduce* the number of vehicle trips and further reduce emissions, while providing a much needed solution to Logan's persistent parking challenge.

Our members, which include 58 colleges and universities with 284,000 students from across the country and around the world and nearly 100,000 faculty, staff and researchers, all rely on Logan for air service to attend education and research conferences, to visit with alumni/ae and to recruit prospective students to attend college here. All this helps to fuel, if not outright define, our globally recognized knowledge-based economy.

If a garage parking spot at Logan is not available, which happens frequently throughout the year, then one is forced to leave one's keys with an attendant, who then parks the car at a different location. Or, one must drive around trying to find parking somewhere else. This creates needless congestion which contributes to emissions and brings vehicles closer to residential neighborhoods. It also most certainly increases the likelihood of missing a flight.

Massport has done an exceptional job investing in alternative modes for accessing the airport, and many of our faculty, staff and students avail themselves of the subsidized services of the Silver Line and Logan Express and other ride sharing options, resulting in a best-in-nation HOV mode share. However, there are still many circumstances where these services are not available or appropriate for our members.

To address current constraints and accommodate future passenger growth, Massport is proposing a measured increase in its on-airport parking as a component of their broader goals of customer service and community and environmental stewardship. We fully support this effort and encourage you to do the same. 6-2

Sincerely,

Richard J Doherty

Richard Doherty, President

ASSOCIATED INDUSTRIES OF MASSACHUSETTS

1 Beacon Street, 16th Floor
Boston, MA 02108

www.aimnet.org | 617.262.1180 | fax 617.536.6785

April 21, 2017

BY HAND

Matthew Beaton
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Page Czepiga, EEA No. 15665
100 Cambridge Street, Suite 900
Boston MA 02114

Dear Secretary Beaton:

On behalf of Associated Industries of Massachusetts (AIM), I am writing to express support for Massport's request to amend the Logan Airport Parking Freeze to add 5,000 parking spaces at the airport. The current situation – where the ability to park at the airport is so uncertain – results in poor customer experience, lost time, potentially missed flights as well as a decrease in air quality.

Founded in 1915, AIM has grown to become the largest employer association in the Commonwealth with more than 4,000 member companies and institutions located throughout the state. Our members represent all industries – manufacturing, financial services, retail, health care, high technology, biotech, education, hospitality, and social services. While we are sometimes perceived as representing large businesses, our average member employs under fifty employees.

Logan Airport is an economic engine for New England, generating more than $13 billion in economic activities annually, and serving 53 international and 75 domestic destinations. In 2016, Logan served a record 36 million passengers, the seventh straight year of passenger growth. Logan's location and the number of direct international flights have been credited in helping Massachusetts secure additional direct foreign investments in our economy, especially in the life sciences, advanced manufacturing and data security sectors.

Our members rely on Logan for both international and domestic business travel, and the advent of additional direct flights have provided our members with additional opportunities to gain access to the global marketplace.

Regarding the need to add an additional 5,000 parking spaces at Logan, if a garage parking spot at Logan is not available, which happens frequently throughout the year, then one is forced to leave one's keys with an attendant, who then parks the car at a different location. Alternatively, one must drive around trying to find parking somewhere else. This creates needless circulation, which contributes to emissions and brings vehicles closer to residential neighborhoods, and certainly increases the likelihood of missing a flight because of the added time from being diverted and then being shuttled back to the terminal from a remote lot.

As an economic engine for the region, Logan needs to enhance its facilities to meet customers' needs as efficiently as possible with minimal impact on the environment and the surrounding neighborhoods. **7-1**

In our view, Massport has done an exceptional job investing in alternative modes for accessing the airport, and many of our members take advantage of the subsidized services of the Silver Line and Logan Express, resulting in a best-in-nation HOV mode share. However, there are still many circumstances where these services are not available or accessible, especially for our members located outside and beyond I 495.

Travelers who cannot access alternative modes and who want to avoid being diverted to a secondary lot often ask a friend or family member to drop them off at the airport and pick them up when they return. That results in four vehicle trips to and from the airport whereas parking only results in two. Due to this, the federal EPA has recognized that a shortage of parking adds to overall vehicle miles traveled.

It is our understanding that Logan Airport is the only airport in the United States that operates under a parking freeze. The original goal of the freeze to reduce Carbon Monoxide (CO) emissions was a worthy one. After decades of technological improvement, emissions overall are down. It appears that raising the cap on the freeze now would reduce the number of vehicle trips and further reduce emissions, while providing a much-needed solution to Logan's persistent parking challenge.

To address current constraints and accommodate future passenger growth, Massport is proposing a measured increase in its on-airport parking as a component of their broader goals of customer service and community and environmental stewardship. We fully support this effort and encourage you to do the same. **7-2**

Sincerely,

Richard C. Lord

Richard C. Lord
President & Chief Executive Officer

Boston Financial Services Leadership Council

AN INITIATIVE OF
Mass Insight
GLOBAL PARTNERSHIPS

Matthew Beaton, Secretary
Executive Office of Energy and Environmental Affairs
Attn: MEPA Office
Page Czepiga, EEA No. 15665
100 Cambridge Street, Suite 900
Boston, MA 02114

Dear Secretary Beaton:

On behalf of The Boston Financial Services Leadership Council, I am writing in support of Massport's request to amend the Logan Airport Parking Freeze to add 5,000 parking spaces at the airport. Massport's proposal is critical to sustaining Massachusetts' important competitive edge in international travel, which provides $1 billion annually to the state's economy.

Massachusetts financial services firms are a key pillar of the state's economy and a major source of jobs, tax revenue and financing for business growth. Most of our businesses have a significant global presence and the connectivity to international markets that Logan provides is essential to our continued leadership in this sector. If a convenient garage parking spot at Logan is not available, which now happens too frequently, one is forced to leave one's keys with an attendant to park the car at a different location. Or, one has to drive around trying to find parking somewhere else, creating practical and environmental impacts.

It is my understanding that Logan Airport is the only airport in the United States that operates under a parking freeze. The original goal of the freeze to reduce carbon monoxide emission was a worthy one. After decades of technological improvement, emissions overall are down. Raising the cap on the freeze at this time would reduce the number of vehicle trips and further reduce emissions, while providing a much needed solution to Logan's persistent parking challenge.

To address this growing parking need and to prepare for the future, Massport is proposing to increase its on-airport parking as a component of the broader goals of customer service and community and environmental stewardship. We appreciate your consideration and fully support this important project for Boston and the New England Region. **8-1**

Sincerely,

William Guenther
Chairman, CEO and Founder
Mass Insight Global Partnerships

18 Tremont Street, Suite 1010. Boston, MA 02108
Tel: 617-778-1500 • Fax: 617-778-1505

April 25, 2017

Matthew Beaton
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Page Czepiga, EEA No. 15665
100 Cambridge Street, Suite 900
Boston MA 02114

Dear Secretary Beaton:

On behalf of the Massachusetts High Technology Council, I am writing to express support for Massport's request to amend the Logan Airport Parking Freeze to add 5,000 parking spaces at the airport. The current situation – where the ability to park at the airport is so uncertain – results in poor customer experience, lost time, potentially missed flights as well as a decrease in air quality. Logan Airport is an essential economic engine for the region, and it needs the capacity in its facilities to meet its customers' needs as efficiently as possible with minimal impact on the environment and surrounding neighborhoods. **9-1**

The Massachusetts High Technology Council represents leading employers from our state's technology and innovation economy. World-class air transportation infrastructure enables our members to access national and international markets and commercial centers and is essential to our members' ability to compete globally and grow their businesses and workforce here in the Commonwealth.

If a garage parking spot at Logan is not available, which happens frequently throughout the year, a traveler is forced to leave car keys with an attendant, who then parks the car at a different location. Or, that traveller must drive around trying to find parking somewhere else. This creates needless circulation which contributes to emissions and brings vehicles closer to residential neighborhoods, and certainly increases the likelihood of missing a flight because of the added time from being diverted and then shuttled back to the terminal from a remote lot.

Massport has done an exceptional job leveraging innovative transportation technologies and investing in alternative modes for accessing the airport. Many of our members take advantage of the subsidized services of the Silver Line and Logan Express, resulting in a best-in-nation HOV mode share. However, there are still many circumstances where these services are not available or accessible for our members traveling via Logan.

It is our understanding that Logan Airport is the only airport in the United States that operates under a decades-old parking freeze. The original goal of the freeze to reduce carbon monoxide emissions was a worthy one. After decades of technological improvement, emissions overall are down. It appears that raising the cap on the freeze at this time would reduce the number of vehicle trips and further reduce emissions, while providing a much needed solution to Logan's persistent parking challenge.

To address current constraints and accommodate future passenger growth, Massport is proposing a measured increase in its on-airport parking as a component of their broader goals of customer service and community and environmental stewardship. We fully support this effort and encourage you to do the same. **9-2**

Sincerely,

Christopher R. Anderson

President

Louis A. Mandarini, Jr.
Business Manager
Secretary Treasurer

Dominic Ottaviano
President
Field Representative

LOCAL 22
CONSTRUCTION & GENERAL LABORERS' UNION

Daniel Ottaviano
Vice President
Field Representative

Michael Cimmino
Recording Secretary
Field Representative

Jonathan Cimino
Executive Board
Field Representative

RECEIVED
APR 20 2017
MEPA

Matthew Beaton
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Page Czepiga, EEA No. 15665
100 Cambridge Street, Suite 900
Boston MA 02114

Dear Secretary Beaton:

On behalf of Laborers' Local 22 I am writing to express support for Massport's request to amend the Logan Airport Parking Freeze to add 5,000 parking spaces at the airport. **10-1**

The proposed two garages are estimated to generate 960 direct, 575 indirect, and 1247 induced FTEs for a total of 2,782 FTEs. These jobs will benefit the economy and provide income for the construction trades.

Construction trades have relied on Massport as a source for jobs in good times and bad. That reliance is important and projects like the two garages will continue it. In addition to economic benefits, the garages will reduce automobile emissions because if a person cannot park, they will rely on drop off and pick up at the airport, resulting in four automobile trips instead of two.

With Logan setting new passenger records every year, there should be some ability to expand parking to respond to the growth the airport has seen. This will not only create jobs, it will benefit the flying public and the environment. **10-2**

Sincerely,

Louis A. Mandarini, Jr.

Dominic C. Ottaviano

35 HIGHLAND AVENUE, MALDEN, MA 02148 • TEL: 781-321-6616 • FAX: 781-321-6662

MACP
MASSACHUSETTS COMPETITIVE PARTNERSHIP

RECEIVED
APR 14 2017
MEPA

April 14, 2017

Matthew Beaton, Secretary
Executive Office of Energy and Environmental Affairs (EEA) 15665
100 Cambridge Street, Suite 900
Boston MA 02114

Dear Secretary Beaton:

On behalf of the Massachusetts Competitive Partnership (MACP), I am expressing my support for Massport's request to amend the Logan Airport Parking Freeze to 5,000 commercial spaces. MACP is a non-profit, public policy group, comprised of the chief executives from some of Massachusetts' largest employers, representing a range of industries. Amending the parking limit can increase Logan Airport's ability to meet customer demand for parking while incurring minimal impact on the environment.

Logan Airport is integral to the overall health of the Commonwealth's economy. By providing the state's businesses access to the international marketplace, Logan allows the state to remain globally competitive. MACP assisted Massport in securing additional nonstop international routes for Logan to meet business demand. As a result of Massport's continual work to upgrade airport, Logan has experienced its seventh straight year of passenger growth, reaching its peak in 2016. The high demand for these flights reflects the business community's reliance on Logan for easy access to global markets.

Because of the high volume of passengers entering Logan each day, parking is often unavailable for customers intending to park at the airport. When parking is unavailable, it results in a needless circulation of vehicles that contributes to emissions. Travelers must either leave their keys with attendants, who move the car to a different location, or they must drive around to search for an open spot - both of which result in an unnecessary release of emissions. Additionally, the potential of missing a flight is increased because of the additional time required to park elsewhere and shuttle to the airport.

In an effort to incentivize reduced travel by personal vehicle, Massport has invested in alternative modes of transportation for passenger access to the airport. Many travelers use the subsidized services of the Silver Line and the Logan Express, both providing high quality HOV mode sharing service. Additionally, Massport has developed partnerships with ride-hailing services such as Uber and Lyft that provide designated pick-up and drop-off areas, further alleviating the parking problem. Despite these

535 Boylston Street, Top Floor | Boston, Massachusetts 02116 | t. 617.236.4099 | f. 617.236.1337 | www.masscompetes.org

preventative steps, there are circumstances where travelers cannot access these modes of transportation, or would prefer an alternative, due to capacity and time constraints. Frequently, travelers will ask a friend or family member to drop them off and pick them up at the airport, resulting in four vehicle trips as opposed to two. It is recognized that a shortage of parking often leads to an increase in the overall miles traveled.

Currently, Logan Airport is the only airport in the United States that operates under a parking freeze in an effort to reduce carbon monoxide emissions. While the goal of reducing emissions is laudable and necessary, raising the cap on the freeze would reduce the number of vehicle trips and redundant travel to and from the airport. This reduction would also reduce emissions, while meeting the demand of Logan's travelers who desire to park.

To address infrastructure constraints and to accommodate future passenger growth, Massport is proposing a measured increase in its on-airport parking as a part of their broader goals of providing high quality customer service and doing so in an environmentally friendly manner. I support Massport's efforts to increase their parking capacity which will better serve the traveler and the environment, simultaneously. **11-1**

Sincerely,

Dan O'Connell
President and CEO
Massachusetts Competitive Partnership

CC: MEPA Office, Page Czepiga, EEA No. 15665

South Shore Chamber of Commerce

April 18, 2017

Matthew Beaton
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Page Czepiga, EEA No. 15665
100 Cambridge Street, Suite 900
Boston MA 02114

Dear Secretary Beaton:

On behalf of the 1300 members of the South Shore Chamber of Commerce I am writing to express support for Massport's request to amend the Logan Airport parking freeze and add 5,000 parking spaces at the airport. Logan Airport is an essential economic engine for the entire region and it needs the capacity in its facilities to meet its customers' needs as efficiently as possible with minimal impact on the environment and the surrounding neighborhoods. 12-1

The South Shore is in the middle of an economic opportunity of a lifetime with the revitalization of downtown Quincy, the build-out of the former Naval Air Station in Weymouth, and the development of Cordage Park in Plymouth to name only a few. In order to attract businesses and residents from outside the region to fuel this growth it is critical we have reliable parking and facilities at Logan. 12-2

Last year the Chamber adopted a regional development strategy which identified MassPort's services as vital to our regional economy. Our regional plan calls for assisting state and local officials in expanding that off-site parking which may include expanded water shuttle service from points on the South Shore to Logan. Massport has done an exceptional job investing in alternative modes for accessing the airport, and many of our members take advantage of services such as the Silver Line and Logan Express in Braintree. However, there are still many circumstances where these services are not available or accessible not to mention the loss of the Harbor Express ferry service from the Quincy Shipyard to Logan in 2013. Consequently, our members who cannot access alternative modes and who want to avoid being diverted to a secondary lot often ask a friend or relative to drop them off at the airport and pick them up when they return. That results in four vehicle trips to and from the airport whereas parking only results in two vehicle trips..

It is my understanding that Logan Airport is the only airport in the United States that operates under a parking freeze. The original goal of the freeze to reduce carbon monoxide

1050 Hingham Street, Rockland, MA 02370
781.421.3900 • Fax: 617.479.9274
www.southshorechamber.org

(CO) emissions was a worthy one and after decades of technological improvement, emissions overall are down. It appears that raising the cap on the freeze at this time would reduce the number of vehicle trips and further reduce emissions, while providing a much needed solution to Logan's persistent parking challenges.

To address current constraints and accommodate future passenger growth, Massport is proposing a measured increase in its on-airport parking as a component of their broader goals of customer service and community and environmental stewardship. We fully support this effort and encourage you to do the same. **12-3**

Sincerely,

Peter Forman

Peter Forman
President & CEO

LETTER 13
pc

RECEIVED
APR 14 2017
MEPA

Matthew K. Barison
124 Coleridge St.
Boston, MA 02128

4/13/2017

Hon. Matthew Beaton
Secretary of Energy and Environmental Affairs
Attn: MEPA Office
100 Cambridge St., Suite 900
Boston, MA 02114

Dear Secretary Beaton:

Thank you for the opportunity to comment on the ENF for the Logan Airport Parking Project. As a resident of East Boston active in multiple community organizations, I have some concerns regarding Massport's request to lift the parking freeze. As you know, East Boston is disproportionately impacted by Logan Airport operations, and with the expansion of Terminal E, we can expect more flights, especially during the night time, when they are the most disruptive. I understand that the Terminal E expansion is a different project from this one, but the two are most certainly related. 13-1

I would like to focus my comments on the current state of public transportation to/from the airport. In addition to Logan Express, which has seen admirable growth and investment by Massport, passengers have the options of traveling to/from the airport on the MBTA's Blue and Silver Lines. The Blue Line connection is somewhat cumbersome, as it involves a shuttle bus transfer between the terminals and Airport station. That said, Massport's use of clean fuel shuttle busses is to be applauded and I support the proposed direct connection of Airport station to the expanded Terminal E. The Blue Line, while a convenient ride to/from Downtown Boston, is limited in its effectiveness, as it does not directly connect with either of the major rail hubs at North and South Stations, and furthermore does not connect with the Red Line.

I would implore that as a condition of lifting the Parking Freeze, the Commonwealth be instructed to move forward with the construction (not further study) of the Red/Blue connector at Charles/MGH, as was originally mandated as mitigation for the Big Dig. This missing link in the MBTA core subway system would encourage individuals from Dorchester, Cambridge, Somerville, the South Shore and beyond to access the airport via the T instead of by auto, and would likely reduce the need for increased airport parking. Massport has the means to fund the construction of this short but critical expansion. Extension of Blue Line service from Wonderland to Lynn would also reduce the number of vehicles traveling to the airport from the North Shore and warrants further exploration. Both of these projects would have benefits far beyond travel to/from the airport, and would be a great way for Massport to pay-it-forward to the communities most impacted by its operations. 13-2 13-3

The Silver Line is likewise sub-optimal. Whereas Massport's commitment to subsidize the purchase of a number of Silver Line busses and provide free access to passengers boarding at the airport is to be lauded, the Silver Line itself is not an efficient means of traveling to/from the airport. The major problem with the Silver Line is that it is subject to traffic within the airport, within the Ted Williams Tunnel, and in the South Boston Seaport district.

The Silver Line would be orders of magnitude more useful if the following improvements were made: (1) signal priority when Silver Line vehicles exit the tunnel in South Boston @ D St., (2) a dedicated MBTA employee at Silver Line Way to assist with the transition from electric to diesel power, rather than the current system which has the bus operator leave the vehicle, (3) access to the TWT Eastbound via the ramp by State Police Station E4 rather than the 13-4
cumbersome loop around the Massport Haul Road (which can increase travel times by up to 15 minutes in heavy traffic), (4) dedicated lanes within the airport, and (5) a new dedicated harbor tunnel between South Boston and Logan Airport solely for the use of the Silver Line and other HOV vehicles. Suggestions #1 and #2 seem easy to implement. Suggestion #3 would save a lot of time without any major infrastructure investments. Suggestion #4 would require some re-engineering of the airport roadway system. Suggestion #5 would be a major undertaking, but a fourth harbor tunnel solely for Silver Line/HOV would ease pressure on the TWT and provide truly rapid transit SL1 service that would be separated from general traffic between South Station and the airport. A dedicated HOV tunnel to the airport would also benefit future Silver Line service to Chelsea, again providing relief to communities most impacted by Massport operations.

The improvements suggested above to the Blue and Silver lines would likely reduce the number of private vehicles traveling to park at Logan Airport. Additional Logan Express routes (coupled with further investments in HOV lanes on major highways) would also reduce the 13-5
demand for parking. Why not try these first before lifting the parking freeze?

If however, your office does decide to lift the parking freeze and allow the construction of 5,000 new spaces at the Central Parking lot and Economy Lot, I would request that Massport 13-6
be required to provide further mitigation to the East Boston community. As these increased parking spaces equate to increased revenue for Massport, these requests are not overly-burdensome from a cost perspective. Furthermore, another easy way to raise revenue for such mitigation projects would be the implementation of a toll for private vehicles entering the airport. As the Commonwealth has now transitioned to AET, it would be easy to erect toll gantries at the airport entrances which assessed a small fee, such as $1, to private, non- 13-7
commercial vehicles entering airport property. These revenues could be earmarked for East Boston mitigation projects.

There are many worthy mitigation projects, and I will suggest just some. A committee of East Boston activists should be convened to determine funding priorities after increased 13-8
revenues from additional parking fees and/or tolls are ascertained. Some suggestions for mitigation include: funding of Piers Park Phase II, extension of the East Boston Greenway, 13-9
modernization of outdated East Boston public schools, supplemental bus service in East Boston

to increase the frequency of current MBTA bus service, Massport subsidization of inner harbor ferries, a new round of window upgrades and soundproofing for residents within certain DNL contours, air filtration to reduce vehicle based emissions within the airport roadway system, a larger cell phone lot, increased electrification of ground access vehicles, supplemental water quality sampling at Constitution Beach, the purchase of vacant lots for the preservation of green space, improvement to landscaping within East Boston, planting of trees, etc. **13-9 Cont.**

In sum, I believe that if Massport is pressed to think big, these additional parking spaces will not be needed. If however, your office concludes otherwise, Massport must give back to the residents of East Boston, who will be the most impacted by increases in traffic and emissions as more vehicles travel to park at the airport.

Thank you for your time and attention.

Sincerely,

Matthew Barison
(617) 620-8244

cc: Stuart Dalzell
Anthony Guerriero
Rep. Adrian Madaro
Sen. Joseph Boncore
Salvatore LaMattina

April 25, 2017

Secretary of Energy and Environmental Affairs
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Page Czepiga, EEA No. 15665
100 Cambridge Street, Suite 900
Boston MA 02114

Via E-mail

Dear Secretary Beaton,

I am writing to express my deep concern over the proposed lifting of the parking freeze at Logan International Airport in order to increase parking by 5,000 spaces. Massport has already successfully broken the freeze and is again attempting this maneuver. The freeze was originally instituted to protect the health and well-being of the impacted communities. This has not changed and Massport should not be allowed to change the definition of "freeze" to suit their purposes.

Massport has stated that one of their reasons for wanting more parking is to reduce the number of drop-off and pick-up trips (kiss and drop) by friends and relatives. If this is true, why has Massport recently allowed Uber and Lyft access to the airport AND given them their own parking lot! Since these are paid parking lots, is this an attempt by Massport to back-door their way around the freeze? **14-1**

As a resident of an Environmental Justice Community, I feel that we are again being short-changed by Massport's lack of producing a comprehensive plan of future expansion so that the entire gamut of health and environmental impacts to our communities may be fully assessed.

For many years members of our community have urged Massport to regionalize flights. At the recent meeting in East Boston one of the union representatives that packed the meeting stated that residents needed to stop being roadblocks to expansion at Logan Airport and allow Boston to become a "world class city." In my opinion, Boston is, and always has been, a "world class city." Tourists and conventioneers come to Boston to visit the city, not the airport. He also listed a number of cities that he considered to be world class. The fact he omitted is that many of those cities have more than one airport. Again, regionalize!

To summarize my points:

- The increased air pollution and noise pollution in our neighborhoods due to increased airplane and vehicular traffic is unacceptable. **14-2**
- The lack of a comprehensive plan for all future expansion planned by Massport needs to be addressed. Cumulative effects cannot be measured adequately when all the projects are presented piecemeal. **14-3**
- A plan to regionalize domestic flights to lessen the impact of increased international flights should be implemented. **14-4**

It is my sincere hope that you will carefully consider these concerns and act in the interests of the people and neighborhoods adversely impacted by airport operations and not allow Massport to feel that any and all projects that they propose will automatically be approved.

Sincerely,

Patricia J. D'Amore
95 Webster Street
East Boston, MA 02128

617-561-4808

pjeandamore@gmail.com

cc: Stewart Dalzell, Deputy Director, Environmental Planning and Permitting, Massport
Sen. Joseph Boncore
Rep. Adrian Madaro
Mayor Martin Walsh via Claudia Correa
Councilor Salvatore LaMattina

Czepiga, Page (EEA)

From: Frederick Salvucci <salvucci@exchange.mit.edu>
Sent: Tuesday, April 25, 2017 3:16 PM
To: Czepiga, Page (EEA)
Subject: Re:: Proposed Logan addition of 5000 parking spaces : April 25, 2017

Dear Secretary Beaton,
Thank you for the opportunity to comment on the ENF on Massport's proposal to add 5000 parking spaces to Logan Airport.
The proposal by Massport should be deferred until a comprehensive set of alternatives should be developed, with public participation, for alternatives to adding parking spaces to an airport which is already generating far too much traffic in the limited capacity of the Cross harbor tunnels. By their own studies, Massport is now causing the generation of 60 to 65 % of the traffic in the Ted Williams Tunnel,, and the Sumner and Callahan tunnel. **15-1**
This statistic raises several disturbing questions:

The Big Dig added significant net new capacity to cross Boston Harbor, and reach Logan Airport, and the communities of East Boston, Winthrop, Revere, and Chelsea.. The Big dig more than doubled this capacity, but it is now becoming congested again only about a decade after completion of the project. This recongestion was not supposed to occur. The combination of the 1989 amended parking limit, and the addition of substantial new transit and Logan express capacity to allow passengers to reach Logan without their cars was supposed to keep the auto growth to not exceed the capacity of the tunnels, and to fairly share the new capacity with the four nearby communities . But Logan auto destinations are growing much too fast, so that the capacity of the tunnels are now frequently exceeded, causing a return of the congestion and air pollution that the Tunnel expansion , along with more transit alternatives ,were supposed to preclude. The net result is a return of congestion and air pollution , and an unfair share of the capacity being dominated by Massport.

It is not news that Massport and Massdot needed to add significant transit opportunities to keep pace with passenger growth, and maintain auto use below reasonable levels. Massport and Massdot have had almost thirty years to achieve the transit investments and other related actions required. The fact that they have failed should not allow them to build more parking, to make more money from parking fees, as a reward for not doing the transit investments required to retain reasonable congestion free flow in the critical tunnels. Let me suggest some actions and studies that Massport should be required to carry out before any consideration should be given to additional parking:

1)Massport should be required to build the underpass for the silver line at D street in South Boston that is required to improve travel time reliability and capacity on the Silver Line connection to Logan airport. This grade separation will enhance the value of the Massport real estate that it rests upon, and would improve the operating conditions of D street necessary to the functioning of the Seaport /Innovation District, where Massport owns significant real estate and seaport assets, and is a reasonable responsibility of Massport. **15-2**

2) Massport should institute any safety inspection required to allow the silver line to use the "state police " ramp, which is the most direct route for the silver Line to Logan, the route that was presented to the public and approved in the environmental process which addd the Silver Line connection to Logan to the South Boston Transitway during the 1990s. **15-3**

3) Massport should reinstitute the direct shuttle from Logan airport Station on the Blue Line to the Logan terminals, with direct services to terminals A and B, and C and E, as existed before Massport modified the routing to introduce the Rent a car facility between the Blue line station and the air terminals, thereby degrading the service which Massport had improved in the 1980s. **15-4**

4) Massport should institute free or very low cost bus service from Logan express sites, at double the current frequencies, and market the opportunity for Logan employees and passengers to be dropped off and picked up by Freinds or taxicabs or Uber and lift or local transit to the Logan Express site, with Massport providing the frequent and convenient and very low cost express bus connection to Logan. **15-5** Massport should also be required to add at least two new Logan Express suburban facilities with at least 2000 parking spaces at suburban locations to improve accessibility to Logan without auto use. **15-6**

5) Massport should introduce an exit fee to access Logan airport, to be collected leectronically from every vehicle which enters Logan, whether they park or not. This fee should be set high enough to reduce auto travel into Logan to below the capacity of the existing garages, and use the revenue to construct new Logan Xpress facilities, and fund increased frequency low cost express bus services from Logan Express to Logan. In addition, the fees should contribute financial support to Masdot to construct the long **15-7**

delayed Blue to Red connector, in order to improve Logan accessibility by transit.Finally this fee should generate a revenue stream to contribute to the proper maintenance of the I -90 and Sumner and Callahan tunnels, which are critical to Logan access. **15-7 Cont.**

6) Massport should initiate a public awareness campaign to notify the public that there is likely to be low parking availability at Logan, and to encourage the use of taxicabs, and Uber and Lyft to access Logan without their autos.. **15-8** Massport lumps together taxicab and Uber and lift acces with drop off and pick up, without recognizing that a well regulated taxi and Uber/lift operation can match the one round trip by auto record of access of parking in the Logan garage. Massport should be required to work first with the taxicab industry to market the taxicab access model for trips not conveniently served by public transit, to give the cabs which have served Logan for decades first crack at this expandable market. **15-9**

7) Massport should initiate free transit passes to all airport employees, similar to the recent initiative at MIT , to encourage Massport and airport and concessionaire employees to use public transportation, and release employee parking spaces for general air passenger use. **15-10**
Massport should also be required to contribute to MBTA all night service that will provide access to Aiport employees during all hours. **15-11**

Massprt should be required to initiate the above actions, and commission independent studies to evaluate the most successful initiatives to be expanded in the future.

Massport should also be required to initiate a new planning process to recognize that they have abandoned the commitments made in the 1980-1990 period to encourage regionalization of air travel demand , and encourage its dispersion to Rhode Island, New Hampshire and Connecticut, and to High speed rail to New York via both Rhode Island and Worcester and Springfield, in order to not over stress the capacity of Logan. Massport should be required to develop anew this regionalization strategy in cooperation with neighboring states and AMTRACK. **15-12**

Massport should be required to do a new conceptual plan for how Logan can possibly handle the air demand that it is generating with its airline subsidy policies, and review the physical constraints of the site. **15-13** Very specifically, there should be no added garage construction at Logan until there is a new master plan that is comprehensive and identifies how the increased level of activity anticipated over the next twenty years can be accommodated on available airport land, and at what cost. **15-14**

Massport should be required to fund independent public health and environmental justice studies of the cumulative impact of current levels of air pollution generated by all Logan related activities, including truck and aviation related NOX and Co2, to establish an honest baseline, against which any new traffic generation will need to be evaluated . It is a long recognized problem in environmental justice communities that it is the toxic mix of pollution from all sources that impacts the health of neighbors, in particular vulnerable neighbors who are elderly, young of rail. So it is essential to establish the current cumulative baseline. Identify means to reduce those levels, and then add the expected increment from any new initiative that may be considered. **15-15**

Massport should be required to fund an independent assessment of the contribution of Logan to climate change gas generation, specifically including aviation generation of Climate change gases like NOX. **15-16**

Thank you for your consideration of these comments.

Frederick P Salvucci

Sent from my iPad

John Vitagliano
19 Seymour Street
Winthrop, MA 02152
Seagullconsult@msn.com

April 25, 2017

Secretary of Energy and Environmental Affairs
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Page Czepiga, EEA No. 15665
100 Cambridge Street, Suite 900
Boston, MA 02114

Dear Secretary Beaton:

I strongly endorse the Massachusetts Port Authority (Massport) 's Environmental Notification Form (ENF) for the Logan Airport Parking Project. I have thoroughly reviewed the entire document and believe that it fully and accurately depicts the current traffic difficulties and environmental degradation associated with ground transportation access to Logan Airport and that it proposes an appropriate remediation program that is simultaneously environmentally responsible and functionally effective. The original Logan parking freeze was implemented some thirty-five years ago when vehicular exhaust emissions were dramatically higher than current levels. Massport's program for adding 5,000 sorely needed parking spaces at Logan Airport would be accommodated in state-of-the-art parking facilities that include substantial numbers of electric vehicle re-charging stations as an incentive for motorists driving emission free vehicles. **16-1**

I have lived in the immediate vicinity of Logan Airport all of my life, Winthrop and East Boston, and would never endorse any proposal for the airport that I felt was environmentally negative in any manner. I urge you to accept Massport's ENF for the Logan Airport Parking Project.

Thank you,

John Vitagliano

Wig Zamore
13 Highland Ave. #3,
Somerville MA 02143
617-625-5630
wigzamore@gmail.com

April 25, 2017

Secretary of Energy and Environmental Affairs
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Page Czepiga, EEA No. 15665
100 Cambridge Street, Suite 900
Boston MA 02114

Via email to: page.czepiga@state.ma.us

Re: **Logan Airport Parking Project ENF 15665**

Dear Secretary Beaton,

Notwithstanding great progress over the last four decades in controlling air and noise pollution in the US, our large and growing regional transportation systems continue to be the largest sector of urban economies whose environmental and health impacts present the most challenges. Barring dramatic increases in personal isolation via more complete reliance on electronic communication, which would have unfortunate social effects, residents and workers of great global cities like Boston cannot easily disentangle themselves from the transportation systems upon which they rely in their daily lives – to work, to shop, to recreate, to learn. And to enjoy family, friends and nature. The opportunities for transportation driven environmental exposures are large. And their management and mitigation very difficult relative to stationary sources.

Logan Airport and its operations are the single largest source of air pollution and noise in New England. **17-1**
Surface transportation is an important component of Logan's local and regional impacts. Those impacts cannot be eliminated, but they must be managed through the collaboration of MassPort, its workers and users, neighbors, and other impacted citizens. **17-2** MassPort has contributed much toward mitigation – through provision of local green space, through support for public transit and other multi-occupancy vehicles, and through adoption of cleaner buildings, lower emission energy sources and streamlined operations such as CONRAC and its new cleaner on-airport bus system. The ENF also details a process that resulted in two well-considered sites for the proposed new customer garages with an additional 5000 customer parking spaces.

Air pollution operates on the environment and health at various spatio-temporal scales – including the very local, regional and global. Although the Clean Air Act initially focused on very local exposures such as carbon monoxide and lead and large particulates, in more recent decades US EPA has focused almost entirely on <u>regional</u> secondary pollutants like ozone and fine particulates. Eastern Massachusetts complies with ozone and PM2.5 NAAQS at this date. However, our ozone standards would be tighter, and Massachusetts likely out of compliance, if CASAC's advice had been more closely followed in recent agency decisions. More ominously, PM2.5 is considered to have NO SAFE THRESHOLD above natural background, and to have a log linear dose response curve. Meaning that halving the pollution does not halve the impacts.

At the very <u>local</u> scale, EPA and those states which rely on EPA's regulatory framework are very far behind current environmental health science. Primary air pollution from large nearby transportation emissions sources has much steeper health impact gradients than regional secondary pollution. Thus local populations living within 50 to 100 meters of large surface roadways, or other similar scale emission facilities, should expect to experience 50% or greater risk, all other factors being equal, of cardiovascular and lung cancer mortality, and of childhood asthma. They should also expect even greater increased risk of autism spectrum disorders in children who spent their first years of life in such locations. Adult cognitive decline is also elevated, and more rapid, in locations near large local transportation emissions sources and facilities.

Regarding global spatio-temporal scale and climate change, transportation is the US economic sector with the single largest impact. Surface transportation is the largest subsector and aviation, as a whole, the fastest growing component in advanced western economies. Scientists and government bodies with in-house science capacity have increasingly focused on Short Lived Climate Pollutants (SLCPs) in their effort to reduce the pace of climate change. This includes focus on sources of Black Carbon such as diesel and Jet A fuel. Per unit of mass, Black Carbon (BC) has 3200 times the impact of emitted CO_2 over twenty years – i.e., GWP20. There is no reason that MassPort, the Boston MPO and MassDEP cannot include SLCPs, most importantly BC, in climate assessments. We do not have to reinvent the science to do this. Just apply it! **17-3**

With regard to the strategy and tactics of Logan related surface transportation, we all need to be braver. Over and over again the Logan Parking ENF refers to the pressure on curb-side Kiss-n-Drop trips whenever there is insufficient garage capacity at Logan. Have we never considered charging for private auto access to Logan for this purpose? MassPort charges for everything but what is most problematic. Now that MassDOT has transponder based highway tolling why not charge for curb-side Kiss-n-Drop? And how much of a charge, **17-4** coterminous with expanded public transit, would be required to obviate the need for any new garages? In all these years of garage and parking freeze expansions, have we not explored and learned the sensitivity of charging for drop off and pick-up trips to Logan. Of course, there are many other tactics to also consider.

Most importantly, Phase 3 of the Urban Ring, before its progress was put on hold, was to have been clean circumferential light rail transit with a projected ridership of roughly 300,000 trips per day, more than the Red or Green Lines, and vastly greater than the whole commuter rail system. Urban Ring Phase 3 would unite the Kendall Square and Longwood Medical Area research economies, provide huge transit capacity to the core through alleviated trips in and out, connect low income service workers with the most expansive parts of Boston's tech and life sciences activities, and intercept all large regional surface radial surface transportation facilities, road and rail based. With implementation of Phase 3 Urban Ring, Logan would not have to build another parking space and our economy, including the struggling Gateway Cities, would hum! **17-5**

MassPort ought to operate Logan with a real target of 50% or greater clean transit and HOV, 50% or less private autos and low occupancy vehicles, and work with all of us to accomplish that as soon as possible. **17-6**

With Best Regards, Wig Zamore

Czepiga, Page (EEA)

From: Wig Zamore <wigzamore@gmail.com>
Sent: Tuesday, April 25, 2017 4:43 PM
To: Czepiga, Page (EEA)
Cc: bill deignan; Fred Salvucci; Andrea Adams; William Legault; david carlon
Subject: Re: Logan Parking ENF Comment15665
Attachments: Koupal 2015 NA Black carbon estimation guide.pdf

The BC Guide - Wig

On Tue, Apr 25, 2017 at 4:42 PM, Wig Zamore <wigzamore@gmail.com> wrote:
I have attached peer reviewed enviromental health science in support of my Logan Parking ENF comment. And a guide to using emissions factors and approved regulatory software to calculate climate impacts of Black Carbon. - Best Regards, Wig Zamore

On Tue, Apr 25, 2017 at 4:25 PM, Wig Zamore <wigzamore@gmail.com> wrote:
Please accept the brief Logan Parking ENF comment attached - Thanks very much, Wig Zamore

Appendix A A-52 DEIR/EA

North American Black Carbon Emissions Estimation Guidelines

2015 International Emissions Inventory Conference
San Diego, CA
April 12-16, 2015

John Koupal, Paula Fields Simms
Eastern Research Group

Orlando Cabrera-Rivera
Commission for Environmental Cooperation

cec.org

ERG

Project Overview

- CEC Project "North American Black Carbon Emission Inventory Guidelines" initiated in November 2013
- Objectives
  - Thorough review and comparison of data and methods
  - Establishment of consensus methodologies to harmonize and improve North American black carbon emissions inventories
  - Incorporation of these into a user-friendly guidance document
- Steering Committee
  - Orlando Cabrera-Rivera, CEC
  - Luis Conde Alvarez, Instituto Nacional de Ecología y Cambio Climático (INECC)
  - Terry Keating, U.S. EPA
  - John Moritz & Francois Lavallee, Environment Canada

Project Team

- ERG
  - John Koupal - Onroad
  - Paula Fields Simms–Residential
  - Richard Billings–Marine/rail/aircraft
  - Rick Baker– Nonroad
  - Regi Oommen– Industrial/Energy
  - Ted Hogan– Expert Consultations
  - Gopi Manne– Literature Review / Guidelines Document
- Veronica Garibay-Bravo (Consultant/Querétaro, Qro) - Mexico Lead
- Dr. Joyce Penner (Consultant/Univ. of Michigan) – Biomass

Project Tasks

- **Task 1:** Review existing black carbon data and methodologies; initial recommendations for North America (Complete)
- **Task 2:** Solicit expert review; consensus methods to harmonize and improve North American black carbon emissions inventories (Complete)
- **Task 3:** Develop guidance document (Draft under review; Final Spring 2015)

Guiding Principles

- Guidance document should be pragmatic about differences between countries in resources, data, and policy needs
- Should identify best-practice approaches, consider how each country can adopt, and include as alternatives or a staged approach for short-term adoption
- Recognize need to identify low-cost recommendations for improving black carbon inventories in Mexico
- The approach to developing emissions inventories depends on the final use of the inventory ("use cases")
- The guidance document must ultimately be understood and accepted by end users

5

Major Sectors and Subsectors

- Biomass Burning
  - Open Burning (e.g. Wildfires)
  - Agricultural Burning
- Mobile Sources
  - On-road
  - Non-road
  - Locomotives
  - Marine
  - Aviation
- Residential
  - Cookstoves, etc.
- Industrial/Energy
  - General
  - Brick kilns (Mexico)
- Other Sources
  - Commercial cooking/ charbroiling
  - Cremation
  - Structure and vehicle fires
  - Municipal solid waste burning

6

Task 1: Review & Initial Recommendations

- Literature Search and Review
  - Databases, abstracts, documents
  - Focused on major, comprehensive inventories, including underlying particular matter (PM) inventories, for North America & Europe

- Divided review into major sectors and primary subsectors
  - Summarized BC and PM inventory approaches
  - Evaluated North American approaches relative to Europe
  - Following IPCC approach, developed general recommendations based on "Tiers"

Master Candidate Document List

- On-line databases → 8,000 studies
- 2004 and later → 1,200 studies
- Available abstract, applicable title → 600 studies
- Final list for review → 140 studies
- Focused on Comprehensive Studies:

Country	Black Carbon Inventory	Underlying PM Inventory
Canada	Assessment of Emissions and Mitigation Options for Black Carbon, Arctic Council, 2011	• NPRI
U.S.	EPA Report to Congress, 2012	• 2002, 2005, 2011 U.S. NEI • RPO Inventories (Biomass)
Mexico	Supporting National Planning of Short-lived Climate Pollutants in Mexico, 2013	2008 Mexico NEI
Europe	EMEP/EEA Air Pollutant Emission Inventory Guidebook, 2013	
Global	• A Technology-based Global Inventory of Black and Organic Carbon Emissions from Combustion (Bond 2004) • Extension of the GAINS model to include SLFCs (Heyes 2011)	

Initial Observations & Judgments

- BC guidelines need to focus on underlying PM emission inventories
- Estimation of BC inventories by speciations of bottom-up PM emissions is the global standard for nearly every sector, as follows:

$$\textit{Black Carbon Mass Emissions} = \textit{PM 2.5 Emission Factor} \times \textit{Activity (or Activity Surrogate)} \times \textit{Speciation Factor}$$

- Emissions data can often be shared across countries, accounting for country-specific controls and factors.
- Activity data are country-specific, and generally obtained from data compiled outside of the agencies responsible for emission inventory development.
- The guidelines should therefore present best practice emission factors by individual sector, to allow inventory developers to focus resources on gathering country-specific activity data.

9

Methods Evaluation

- North American approaches evaluated vs. EMEP/EEA Tiers (1, 2, 3)
- Example evaluation matrix:

Sector/Subsector: Mobile Sources/On-Road

	Euro Tier 1	Euro Tier 2	Euro Tier 3	< Tier 1	Tier 1	Tier 2	Tier 3	> Tier 3
Method	Aggregate fuel based PM	Refined fuel-based PM w/ speciation	Detailed bottom-up PM w/speciation				Canada ACTF; Mexico NEI (MOBILE6)	EPA RTC (MOVES calculates EC directly)
Emission Factors	Single fuel-based factor	Technology-specific fuel-based	BC/EC emission factors by vehicle class, model year/standard			Canada ACTF & Mexico NEI (MOBILE6)	EPA RTC (MOVES)	
Activity	Total fuel consumed	Fuel consumed by technology	VMT by vehicle class, roadway, speed				EPA RTC (MOVES); Canada ACTF; Mexico NEI	
Speciation	N/A	Technology-specific factor	Technology-specific factor				Canada ACTF; Mexico NEI (SPECIATE)	EPA RTC (MOVES w/speciation by activity)

10

Initial Recommendations

- Develop initial recommendations for North American Tiers based on data available in Canada, U.S. and Mexico – example:

Sector/Subsector: Mobile Sources/On-road

	Recommended North American Tier 1	**Recommended North American Tier 2**	**Recommended North American Tier 3**
Method	Aggregate fuel-based approach, based on a single national estimate of fuel consumption (by fuel type, i.e. gasoline, diesel, CNG, etc.) by calendar year. Off-model calculation.	Refined fuel-based approach, based on estimates of fuel consumption by fuel type and vehicle class, (i.e. car, light truck, bus, heavy truck). Off-model calculation.	Detailed activity-based approach, using MOVES customized to individual country emission standards and using country-specific data on vehicle activity etc.
Emission Factors	MOVES aggregated to a single fuel-based black (elemental) carbon emission factor, by calendar year. For Canada and Mexico, apply MOVES International approach to adjust for differences in vehicle emission standards	MOVES aggregated to a fuel-based black (elemental) carbon emission factor, by vehicle class and calendar year. For Canada and Mexico, apply MOVES International approach to adjust for differences in vehicle emission standards	Use MOVES directly to estimates black (elemental) carbon emission factor. For Canada and Mexico, develop MOVES International to account for differences in vehicle emission standards. Customize model with country-specific inputs for VKT, average speeds, fuels, vehicle age, and meteorology
Activity	Total fuel consumed – by fuel type only (gasoline, diesel, CNG, etc.)	Fuel consumed by vehicle class and calendar year	VMT or VKT by vehicle class, roadway and average speed
Speciation	Not needed, if MOVES elemental carbon emission factor is used	Not needed, if MOVES elemental carbon emission factor is used	Not needed, if MOVES elemental carbon output is used

Task 2: Expert Consultations

- Expert panel recruited for coverage by emissions sectors, countries
- Results of Task 1 shared for review
- Series of webinars held in Fall 2014 to solicit input
  - Online surveys sent prior to each webinar
- Meeting with Mexico Panel Members & INECC held in Mexico City
- Written comments also requested

Expert Panel Members

Name	Employer/Organization
José Andrés Aguilar	INECC (Mexico)
Luisa Molina	Molina Center of Energy and the Environment (Mexico)
John Crouch	Hearth, Patio and Barbeque Association (U.S.)
Michelle Bergin	Duke University (U.S.)
Santa Centeno	INECC (Mexico)
Xochitl Cruz Nunez	UNAM (Mexico)
Beatriz Cardenas	Comision Ambiental de la Megalópolis (Mexico)
Luis Gerardo Ruiz Suarez	UNAM (Mexico)
Carlo Trozzi	Techne Consulting (Italy)
Karin Kindbom	IVL Swedish Environmental Research Institute (Sweden)
Vankatesh Rao	U.S. EPA/OAR (U.S.)
Darrell Sonntag	U.S. EPA/OAR (U.S.)
Nancy French	Michigan Tech Research Institute (U.S.)
Jessica McCarty	Michigan Tech Research Institute (U.S.)
Wei Min Hao	U.S. Forest Service (U.S.)
Jim Jetter	U.S. EPA/ORD (U.S.)
Bob Yokelson	University of Montana (U.S.)
Min Huang	Caltech/JPL (U.S.)
Don Stedman	University of Denver (U.S.)
Serena Chung	Washington State University (U.S.)
Sean Raffuse	Sonoma Technology, Inc. (U.S.)
Fang Yan	Argonne National Laboratory (U.S.)
Brooke L. Hemming	U.S. EPA/ORD (U.S.)
Edward Hyer	Naval Research Laboratory (U.S.)
Abraham Ortinez	INECC (Mexico)
Jason Blake Cohen	National University of Singapore (Singapore)
Peter Sheldon	Global Fire Monitoring Center (Germany)
Joshua Schwarz	CIRES/NOAA (U.S.)
Steigvile Bycenkiene	Center for Physical Sciences and Technology (Lithuania)
Savitri Garivait	JGSEE-KMUTT (Thailand)
Matthew Johnson	Carleton University (Canada)

Expert Panel Input - Highlights

- Reflect that speciation factors are a major source of uncertainty in BC inventories
- Address uncertainty
- Reflect recent updates in Mexico (e.g. 2013 SNAP)
- Address temporal resolution
- Include newer studies, esp. for Biomass
  - Since EPA Report to Congress, updated methods contained in the biomass burning section of the U.S. NEI for 2008 and 2011
- Add Municipal Solid Waste burning as a subsector

14

Task 3: Develop Guidelines

- Guidelines for practitioners to produce BC inventories for major subsectors
- Approaches provided for Tier 1 / 2 /3 , depending on purpose of inventory and data availability

Tier	National Reporting	Regional Inventories	Impact Analyses	Mitigation Analyses
1	✓	✓		
2	✓	✓		✓
3		✓	✓	✓

- For each Tier, sources of activity, emission factor and speciation data identified for Canada, U.S. and Mexico
- Schedule
  - Draft complete – under review
  - Final Spring 2015

15

Guidance Document Outline

- Overview of Methods Review & Expert Panel Input
- Use of the Guidelines
  - Inventory Use Cases
  - Considerations: Speciation, Spatial/Temporal Resolution
  - Organization: Tier Framework
- Black Carbon Estimation Methods (by subsector)
  - Source Category Description
  - Tie r 1, Tier 2 & Tier 3 Methods for estimating emissions
  - Tier 1, Tier 2 & Tier 3 Data Sources for Canada, United States & Mexico: Activity, Emissions Factors, Speciation Factors
- Emissions Data Management
- Validation & Uncertainty
- Recommendations for Further Research

Parameter	Canada	U.S.	Mexico
Tier 1			
Average values for: • Area burned • Yield (avg.) • Residue: yield • Dry matter content • Portion of residue burned • Combustion factor	• Area burned (McCarty 2011, remote sensing) or local agency reports • Residue loading by crop: EMEP/EEA 2013, Table 3-2; Schreuder and Mavko 2010; van Leeuwen et al. 2014; WRAP 2005 • Combustion factor data: Van Leeuwen et al. 2014; Akagi et al. 2011		• Area burned: National Union of Sugarcane Harvesters (*Unión Nacional de Cañeros A.C.), Estadísticas de la Agroindustria Azucarera Nacional* • Annual production per crop: Agriculture and Food Produce Information System (SIACON)(SAGARPA 2013)
Emission factor ($PM_{2.5}$)	Table 3-1 (EMEP/EEA 2013); Schreuder and Mavko 2010; van Leeuwen et al. 2014; Akagi et al. 2011; WRAP 2005		Akagi et al. 2011 For sugarcane: Hall et al. 2012
Speciation factor (BC)	Average BC fraction: SPECIATE database (Figure 4-1, EPA 2013a; use EC factor for BC); WRAP 2005		Average BC fraction: SPECIATE database (Figure 4-1, EPA 2013a; use EC factor for BC)
Tier 2			
By crop type: • Area burned • Yield (avg.) • Residue: yield • Dry matter content • Portion of residue burned • Combustion factor	• Area burned (McCarty 2011, using remote sensing) and local agency reports • Residue loading by crop: Schreuder and Mavko 2010; van Leeuwen et al. 2014; 2002 Fire Emission Inventory for the WRAP Region—Phase II report 2005 • Combustion factor data: van Leeuwen et al. 2014; Akagi et al. 2011		• Area burned: National Union of Sugarcane Harvesters (*Unión Nacional de Cañeros A.C.), Estadísticas de la Agroindustria Azucarera Nacional* • Annual production per crop: Agriculture and Food Produce Information System (SIACON) (SAGARPA 2013) • Residue loading by crop and combustion factor data: none available
Crop-specific emission factor ($PM_{2.5}$)	Schreuder and Mavko 2010; van Leeuwen et al. 2014; Akagi et al. 2011; WRAP 2005		For sugarcane: Hall et al. 2012
Crop-specific speciation factor (EC/BC)	See Tier 1		
Tier 3			
By crop type: • Area burned • Yield (avg.) • Residue: yield • Dry matter content • Portion of residue burned • Combustion factor	• Area burned (McCarty 2011, using remote sensing) and local agency reports • Residue loading by crop: Schreuder and Mavko 2010; van Leeuwen et al. 2014; WRAP 2005 • Combustion factor data: van Leeuwen et al. 2014; Akagi et al. 2011		See Tier 2
Crop-, climate, and soil-specific emission factor ($PM_{2.5}$)	Schreuder et al. 2010; van Leeuwen et al. 2014; Akagi et al. 2011; WRAP 2005		For sugarcane: Hall et al. 2012
Crop-specific speciation factor (BC)	See Tier 1		

Example : Recommended Data Sources by Country & Tier (Agricultural Burning)

Recommended Black Carbon Inventory Improvements - Highlights

- Develop BC emission factors directly
  - Current speciation approach increases error
- Biomass
  - Improved satellite instruments
  - Spatially accurate fuel load data
  - Account for moisture
- Onroad
  - Improve vehicle activity data in Mexico & Canada
  - Adapt MOVES emission rates to Mexico & Canada
- Nonroad
  - Develop standardized source of population & activity in Mexico & Canada
  - Develop more representative emissions factors for aircraft, marine vessels and locomotives

Recommended Black Carbon Inventory Improvements – Highlights, Cont.

- Brick Kilns
  - Develop brick production & efficiency estimates by region in Mexico
  - Develop emission factors by wood & fuel oil
- Residential
  - Conduct surveys of wood use by municipality
  - More representative emissions factors for open fires and cookstoves

Summary

- The Commission for Environmental Cooperation (CEC) is sponsoring the development of Black Carbon emissions estimation guidelines for North America
- Guidelines are based on review of Black Carbon & underlying PM inventories in North America, Europe and Asia
- Guidelines suggest methods and data sources for major emission sectors/subsectors in Canada, Mexico and the United States
- Following IPCC template, 3 Tiers are defined based on inventory purpose and data availability
- Final guidelines will be available Spring 2015

20

Contacts

- **Orlando Cabrera-Rivera (CEC)** ocabrera@cec.org
- **John Koupal (ERG)** john.koupal@erg.com

Czepiga, Page (EEA)

From: Wig Zamore <wigzamore@gmail.com>
Sent: Tuesday, April 25, 2017 4:42 PM
To: Czepiga, Page (EEA)
Cc: bill deignan; Fred Salvucci; Andrea Adams; William Legault; david carlon
Subject: Re: Logan Parking ENF Comment15665
Attachments: Pope 2015 JAWMA Health benefits of air pollution abatement policy Role of the shape7 of the concentration response function.pdf; Burnett 2014 EHP An integrated risk function for estimating the Global Burden of Disease attributable to ambient fine PM.pdf; Gan 2010 EPID Changes in residential proximity to road traffic and the risk of death from coronary heart disease.pdf; Gauderman 2005 EPIDEM Childhood Asthma and Exposure to Traffic and Nitrogen Dioxide.pdf; Nyberg 2000 EPIDEM Urban Air Pollution and Lung Cancer in Stockholm.pdf; Volk 2012 AGP Traffic related air pollution particulate matter and autism.pdf

I have attached peer reviewed enviromental health science in support of my Logan Parking ENF comment. And a guide to using emissions factors and approved regulatory software to calculate climate impacts of Black Carbon. - Best Regards, Wig Zamore

On Tue, Apr 25, 2017 at 4:25 PM, Wig Zamore <wigzamore@gmail.com> wrote:
Please accept the brief Logan Parking ENF comment attached - Thanks very much, Wig Zamore

All *EHP* content is accessible to individuals with disabilities. A fully accessible (Section 508–compliant) HTML version of this article is available at http://dx.doi.org/10.1289/ehp.1307049.

An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure

Richard T. Burnett,[1] C. Arden Pope III,[2] Majid Ezzati,[3] Casey Olives,[4] Stephen S. Lim,[5] Sumi Mehta,[6] Hwashin H. Shin,[1] Gitanjali Singh,[7] Bryan Hubbell,[8] Michael Brauer,[9] H. Ross Anderson,[10] Kirk R. Smith,[11] John R. Balmes,[12,13] Nigel G. Bruce,[14] Haidong Kan,[15] Francine Laden,[16] Annette Prüss-Ustün,[17] Michelle C. Turner,[18] Susan M. Gapstur,[19] W. Ryan Diver,[19] and Aaron Cohen[20]*

[1]Health Canada, Ottawa, Ontario, Canada; [2]Brigham Young University, Provo, Utah, USA; [3]MRC-PHE Centre for Environment and Health, School of Public Health, Imperial College London, London, UK; [4]School of Public Health, University of Washington, Seattle, Washington, USA; [5]Institute for Health Metrics and Evaluation, Seattle, Washington, USA; [6]Global Alliance for Clean Cookstoves, Washington, DC, USA; [7]Harvard School of Public Health, Harvard University, Cambridge, Massachusetts, USA; [8]U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, USA; [9]School of Population and Public Health, University of British Colombia, Vancouver, British Columbia, Canada; [10]MRC-PHE Centre for Environment and Health, King's College London, London, UK; [11]University of California, Berkeley, Berkeley, California, USA; [12]School of Medicine, University of California, San Francisco, San Francisco, California, USA; [13]School of Medicine, University of California, Berkeley, Berkeley, California, USA; [14]Department of Public Health and Policy, University of Liverpool, Liverpool, UK; [15]School of Public Health, Fudan University, Shanghai, China; [16]Exposure, Epidemiology, and Risk Program, Department of Environmental Health, Harvard School of Public Health, Boston, Massachusetts, USA; [17]World Health Organization, Geneva, Switzerland; [18]Institute of Population Health, University of Ottawa, Ottawa, Ontario, Canada; [19]American Cancer Society, Atlanta, Georgia, USA; [20]Health Effects Institute, Boston, Massachusetts, USA

*Senior Author

Background: Estimating the burden of disease attributable to long-term exposure to fine particulate matter ($PM_{2.5}$) in ambient air requires knowledge of both the shape and magnitude of the relative risk (RR) function. However, adequate direct evidence to identify the shape of the mortality RR functions at the high ambient concentrations observed in many places in the world is lacking.

Objective: We developed RR functions over the entire global exposure range for causes of mortality in adults: ischemic heart disease (IHD), cerebrovascular disease (stroke), chronic obstructive pulmonary disease (COPD), and lung cancer (LC). We also developed RR functions for the incidence of acute lower respiratory infection (ALRI) that can be used to estimate mortality and lost-years of healthy life in children < 5 years of age.

Methods: We fit an integrated exposure–response (IER) model by integrating available RR information from studies of ambient air pollution (AAP), second hand tobacco smoke, household solid cooking fuel, and active smoking (AS). AS exposures were converted to estimated annual $PM_{2.5}$ exposure equivalents using inhaled doses of particle mass. We derived population attributable fractions (PAFs) for every country based on estimated worldwide ambient $PM_{2.5}$ concentrations.

Results: The IER model was a superior predictor of RR compared with seven other forms previously used in burden assessments. The percent PAF attributable to AAP exposure varied among countries from 2 to 41 for IHD, 1 to 43 for stroke, < 1 to 21 for COPD, < 1 to 25 for LC, and < 1 to 38 for ALRI.

Conclusions: We developed a fine particulate mass–based RR model that covered the global range of exposure by integrating RR information from different combustion types that generate emissions of particulate matter. The model can be updated as new RR information becomes available.

Citation: Burnett RT, Pope CA III, Ezzati M, Olives C, Lim SS, Mehta S, Shin HH, Singh G, Hubbell B, Brauer M, Anderson HR, Smith KR, Balmes JR, Bruce NG, Kan H, Laden F, Prüss-Ustün A, Turner MC, Gapstur SM, Diver WR, Cohen A. 2014. An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. Environ Health Perspect 122:397–403; http://dx.doi.org/10.1289/ehp.1307049

Introduction

Long-term exposure to ambient fine particulate matter (≤ 2.5 μg/m^3 in aerodynamic diameter; $PM_{2.5}$) is associated with increased mortality from nonaccidental and cause-specific diseases (Brook et al. 2010; Committee on the Medical Effects of Air Pollutants 2009; Cooke et al. 2007; Krewski et al. 2009). Epidemiologic cohort studies, conducted largely in the United States, have reported this association for annual ambient average concentrations from approximately 5 to 30 μg/m^3, although definitive knowledge of which specific sources or characteristics of $PM_{2.5}$ are responsible for these associations is currently lacking [U.S. Environmental Protection Agency (EPA) 2009; World Health Organization (WHO) 2006, 2007]. No epidemiologic study, however, has estimated the association of long-term exposure to direct measurements of $PM_{2.5}$ with mortality from chronic cardiovascular and respiratory disease at the higher ambient exposures common in cities and other areas in Asia and other developing countries where annual average exposures can exceed 100 μg/m^3 (Brauer et al. 2012; Health Effects Institute 2010). As a result, estimates of disease burden attributable to ambient air pollution in these locations have had to be based on extrapolations of the results of epidemiologic studies from locations with lower ambient $PM_{2.5}$ exposures (Anenberg et al. 2010; Cohen et al. 2004; Evans et al. 2013).

Previous efforts to estimate global burden from exposure to ambient air pollution (AAP) in the form of $PM_{2.5}$ postulated risk

Address correspondence to R.T. Burnett, Population Studies Division, Environmental Health Sciences and Research Bureau, Environmental and Radiation Health Sciences Directorate, Healthy Environment and Consumer Safety Branch, Health Canada, Room 134, Environmental Health Center, 50 Columbine Driveway, Ottawa, Ontario, Canada K1A 0K9. Telephone: (613) 952-1364. E-mail: rick.burnett@hc-sc.gc.ca

Supplemental Material is available online (http://dx.doi.org/10.1289/ehp.1307049).

We thank the members of the Ambient Air Pollution Expert Group of the Global Burden of Diseases, Injuries, and Risk Factors Study for their helpful comments and discussion of this material and M. Lipsett for the relative risk estimate for chronic obstructive pulmonary disease mortality from the California Teachers Study.

A.C. received support from the William and Flora Hewlett Foundation.

A.C. is employed by the Health Effects Institute (HEI). The HEI receives about half of its core funds from the U.S. Environmental Protection Agency and half from the worldwide motor vehicle industry, although other public and private organizations periodically support special projects or certain research programs. The views expressed in this article do not represent those of the HEI or its sponsors. A.P.-U. is a staff member of the World Health Organization (WHO), and the views expressed in this article do not necessarily represent the views, decisions, or policies of the WHO. This article should not be reproduced for use in association with the promotion of commercial products, services, or any legal entity. The WHO does not endorse any specific organization or products. Any reproduction of this article cannot include the use of the WHO logo.

The authors declare they have no actual or potential competing financial interests.

Received: 6 May 2013; Accepted: 7 February 2014; Advance Publication: 11 February 2014; Final Publication: 1 April 2014.

functions for cardiopulmonary mortality as linearly increasing in relative risk (RR) from 7.5 to 50 μg/m^3, with no further change in RR at higher concentrations (Cohen et al. 2004). Sensitivity analyses included a model in which RR varied as the logarithm of concentration, producing a more gradual diminution of the marginal increase in RR than the base case model. The logarithmic model was subsequently recommended by the WHO for use in air pollution burden of disease estimates at the national level (Ostro 2004). The coefficients of these models were based on information from a single U.S. cohort study—the American Cancer Society Cancer Prevention Study II (CPS-II) (Krewski et al. 2009; Pope et al. 2002)—with exposure assignments of < 22 μg/m^3. The form of the models used for global burden assessment was motivated largely by the concern that linear extrapolation using these coefficients would produce unrealistically large estimates of RR compared with other known $PM_{2.5}$-related mortality risks such as active smoking (AS) and exposure to secondhand tobacco smoke (SHS) (Cohen et al. 2004; Ostro 2004). These RR models were also employed in more recent estimates of global mortality associated with ambient $PM_{2.5}$ concentrations (Anenberg et al. 2010; Evans et al. 2013).

Absent empirical epidemiologic evidence on the magnitude of the association with mortality at high exposures of $PM_{2.5}$ in ambient environments, Pope et al. (2011b) suggested that the integration of epidemiologic evidence on cardiovascular and lung cancer (LC) mortality RR from disparate types of $PM_{2.5}$ exposure such as AAP, SHS, and AS, may provide insight into the shape of the exposure–response relation over a much wider range of exposures.

Here we present the methodology used to estimate the population attributable fraction (PAF) from exposure to ambient $PM_{2.5}$ in the Global Burden of Diseases, Injuries, and Risk Factors Study 2010 (the GBD 2010 project) (Lim et al. 2012). We selected a mathematical form of the RR function with a $PM_{2.5}$ concentration that could describe the observed relationships between RR and exposure for the five outcomes examined. We fit this model for cause-specific adult mortality for four causes of death—ischemic heart disease (IHD), stroke, chronic obstructive pulmonary disease (COPD), and LC—using RR information from epidemiologic studies of long-term exposure to particulate matter not only from AAP, SHS, and AS, but also from studies of household air pollution from solid cookfuel (household air pollution; HAP). We used these models to estimate the percentage of PAF associated with exposure to ambient $PM_{2.5}$ for each of the 187 countries included in the GBD 2010 project. We identified a specific model form that best predicts source-specific RR for all four causes of death. In addition, we examined the relationship between $PM_{2.5}$ exposure and the incidence of acute lower respiratory infection (ALRI) in infants, another health outcome considered in the GBD 2010 project. Because infants and young children are non(active)-smokers, the largest $PM_{2.5}$ exposures considered for ALRI are from HAP.

Methods

Underlying assumptions. The model we propose in here was based on the following underlying assumptions:

- Exposure to $PM_{2.5}$ from diverse combustion sources is associated with increased mortality from IHD, stroke, COPD, and LC and with increased incidence of ALRI. This assumption is based on systematic review of the available epidemiologic literature conducted by the GBD 2010 Ambient Air Pollution Expert Group as part of the GBD 2010 project (Lim et al. 2012).
- The observed RRs from AAP, SHS, HAP, and AS are a function of $PM_{2.5}$ mass inhaled concentration across all combustion particle sources (Smith 1987). The toxicity of $PM_{2.5}$ is assumed to differ only with regard to inhaled mass (exposure) and not with $PM_{2.5}$ composition. The toxicity of emissions from different combustion sources may well differ, but current knowledge does not allow definitive and quantifiable conclusions regarding their relative toxicity and little is known about international variation in source contributions around the world (Stanek et al. 2011; U.S. EPA 2009; WHO 2006).
- The relation between $PM_{2.5}$ exposure and excess mortality RR is not necessarily restricted to a linear function over the range of human exposure to $PM_{2.5}$ from diverse sources (Pope et al. 2009, 2011b).
- The RR of mortality from chronic disease experienced by people exposed to AAP, SHS, HAP, and AS is a function of long-term, cumulative exposure quantified in terms of daily average exposure concentration and does not depend on the temporal pattern of exposure (Pope et al. 2011a, 2011b). This assumption is required because the temporal nature of $PM_{2.5}$ exposure differs for AAP, SHS, HAP, and AS.
- The RR associated with each type of exposure does not depend on the other types of exposure. That is, we are assuming no interaction among the different exposure types for any cause of mortality. We are aware of no empirical epidemiologic evidence that tests that assumption; however, the direct epidemiologic evidence from the cohort studies we used to estimate the burden attributable to ambient $PM_{2.5}$ shows that active cigarette smokers are also affected adversely by exposure to ambient $PM_{2.5}$, and these studies do not provide support for significant heterogeneity of the relative excess AAP RR across smoking categories.

Model form. We selected a mathematical form of an integrated exposure–response (IER) model that could describe several patterns in RR thought to be *a priori* applicable to exposure–response models. We wanted the IER to be able to take shapes similar to models previously used for burden assessment, such as linear and log-linear (Cohen et al. 2004) and a power function (Pope et al. 2009, 2011b). In addition to these shapes, we also required the IER to have a property that it flattens out at high exposures, consistent with evidence of the relationship between IHD mortality and smoking intensity (Pope et al. 2009).

The form must equal 1 when $PM_{2.5}$ values are below some concentration that represents a counterfactual low exposure where below this level there is no excess risk. We also desired a model that increases monotonically with increasing $PM_{2.5}$ exposure concentration and could take a variety of shapes, such as near linear, sublinear, and supralinear. Our IER model has the following form:

for $z < z_{cf}$,
$RR_{\mathrm{IER}}(z) = 1$

for $z \geq z_{cf}$,
$$RR_{\mathrm{IER}}(z) = 1 + \alpha\,\{1 - \exp[-\gamma\,(z - z_{cf})^{\delta}]\}, \quad [1]$$

where z is the exposure to $PM_{2.5}$ in micrograms per meter cubed and z_{cf} is the counterfactual concentration below which we assumed there is no additional risk. For very large z, RR_{IER} approximates $1 + \alpha$. We included a power of $PM_{2.5}$, δ, to predict risk over a very large range of concentrations. Further, $RR_{\mathrm{IER}}(z_{cf} + 1)$ approximates $1 + \alpha\gamma$. Thus, $\gamma = [RR_{\mathrm{IER}}(z_{cf} + 1) - 1]/[RR_{\mathrm{IER}}(\infty) - 1]$ can be interpreted as the ratio of the RR at low-to-high exposures. We term our model an "integrated-exposure response" model because its development requires the integration of exposures to $PM_{2.5}$ from different combustion types (i.e., AAP, SHS, HAP, and AS).

In formulating our RR model, we relied on information on the RR of mortality at specified $PM_{2.5}$ exposure concentrations from the available literature. Suppose we have a set of RR estimates $\{\hat{r}_1^{(s)},\ldots,\hat{r}_{K_s}^{(s)}, s = 1,\ldots,S\}$ and corresponding confidence intervals (CIs) based on $PM_{2.5}$ concentrations $\{z_1^{(s)},\ldots,z_{K_s}^{(s)}, s = 1,\ldots,S\}$, for S different types of $PM_{2.5}$ sources, where K_s is the number of RR estimates available from for source type S. The unknown parameters (α, γ, δ) are estimated by nonlinear regression methods. We then weighted the RR estimates by the inverse of the variance estimate of the logarithm of the RR in order to reflect the uncertainties in each estimate.

We compared the IER model to seven other models that have been previously suggested for burden assessment. These include an RR model that is linear in exposure throughout the global concentration range (Lin), a model that is linear up to 30 μg/m^3 and constant above 30 μg/m^3 (Lin30), a model that is linear up to 50 μg/m^3 and constant above 50 μg/m^3 (Lin50), and a model that is a function of the logarithm of exposure (Log). These models were used in a previous assessment of global burden of disease due to AAP exposure (Cohen et al. 2004). We also postulated a model in which we added an unknown parameter to concentration in the Log model to allow more flexibility in fitting the type-specific RRs (Log2). The sixth model examined related RR to a power of exposure as proposed by Pope et al. (2009, 2011b), with the seventh model equivalent to the IER with δ = 1(Exp). For the mathematical forms of the models, see the Supplemental Material (Sensitivity of RRs and PAFs to Model Form, pp. 9–11). We then calculated both the Akaike and Bayesian information criteria (AIC, BIC) for each of the eight models examined and five health outcomes as measures of goodness of fit.

The method of constructing uncertainty bounds on model predictions is described in detail in the Supplemental Material (Characterizing Uncertainty, pp. 28–29). Briefly, we simulated 1,000 sets of source type–specific RRs based on their point estimates and CIs and fit the IER model to these simulated values, obtaining 1,000 sets of parameter estimates of (α,γ,δ). Using these parameter estimates, we then generated 1,000 IER functions over the global concentration range. Estimates of uncertainty were also generated for the $PM_{2.5}$ concentrations. Uncertainty in the PAFs is a function of the uncertainty in the IER model predictions and the exposure estimates and is determined by simulation methods as described in the Supplemental Material (Characterizing Uncertainty, pp. 28–29).

Specifics of the selection of source type–specific RR and $PM_{2.5}$ exposure for each type are described below for the four mortality outcomes. The logarithm of the RR per micrograms per meter cubed, its SE, and associated $PM_{2.5}$ concentration for the five outcomes is given by type of $PM_{2.5}$ in Supplemental Material, Table S1.

AAP. To fit the risk models, we used cause-specific mortality AAP RR estimates from available published cohort studies. We evaluated each RR estimate at its study-specific $PM_{2.5}$ mean concentration minus a less-polluted counterfactual level (Lim et al. 2012). Most RRs were obtained from published reports; however, in some cases new analyses were conducted for the present study. These estimates are identified in Supplemental Material, Table S1. We had eight studies reporting RR estimates for IHD mortality, five for stroke mortality, three for COPD mortality, and four for LC mortality.

SHS. We selected RRs for both IHD (8 studies reporting separate estimates for males and females) and LC (46 studies) mortality from studies included in the U.S. Surgeon General's Report, *The Health Consequences of Involuntary Exposure to Tobacco Smoke* (Office on Smoking and Health 2006). We associated the RR of death due to SHS exposure with an equivalent ambient $PM_{2.5}$ concentration of 20 μg/m^3 for low-to-moderate SHS exposure and 50 μg/m^3 for moderate-to-high exposure based on the analysis of Pope et al. (2009) for IHD mortality because RRs were reported by the Office on Smoking and Health (2006) for these two descriptive exposure categories. We assigned a concentration of 35 μg/m^3 based on the midpoint of the range 20–50 μg/m^3 for LC mortality because no specific description of the level of SHS exposure was provided by the Office on Smoking and Health (2006). We selected 29 RRs from studies examined by Oono et al. (2011) for stroke mortality on the basis of prospective cohort studies with an associated $PM_{2.5}$ concentration of 35 μg/m^3. There was insufficient evidence to estimate a RR due to SHS exposure for COPD mortality. We assumed that the SHS RRs are associated with a change in $PM_{2.5}$ exposure based on nonsmoking subjects living with a smoker compared with those not living with a smoker. We have not incorporated other potential sources of $PM_{2.5}$ exposure for these study subjects, such as from indoor sources, near-roadway conditions, or occupational exposures by subject.

AS. Following Pope et al. (2009, 2011b), we estimated the RR of each of the four causes of death for current cigarettes smoked per day compared with never smokers from the CPS-II. We estimated the RR and 95% CIs associated with 10 cigarettes-per-day groupings: 1–3, 4–7, 8–12, 13–17, 18–22, 23–27, 28–32, 33–37, 38–42, and > 42 cigarettes/day. We estimated that smoking a single cigarette was equivalent to breathing a daily ambient concentration of $PM_{2.5}$ of 667 μg/m^3, assuming an average breathing rate of 18 m^3/day and an inhaled dose of 12,000 μg $PM_{2.5}$ mass per cigarette (Pope et al. 2009). We then estimated the equivalent ambient concentration of $PM_{2.5}$ by multiplying the average cigarettes/day smoked in each interval by 667 μg/m^3. The shape of the curve fitted by Pope et al. (2009, 2011b) was not sensitive to the estimate of equivalent ambient $PM_{2.5}$ concentrations for AS.

HAP. Smith et al. (2014) conducted a meta-analysis of studies examining COPD and LC incidence rates among men and women exposed to air pollution from burning coal or biomass for cooking. There were no studies relating IHD or stroke mortality or incidence to HAP at the time of the GBD 2010 project analyses, and thus this $PM_{2.5}$ type cannot contribute to the fit of our RR function. The equivalent long-term $PM_{2.5}$ exposure from HAP was estimated for study subjects using coal or biomass for cooking (Balakrishnan et al. 2013) and for those study subjects using cleaner fuels to integrate this information into our IER risk model. $PM_{2.5}$ exposure estimates for women (300 μg/m^3) were higher than for men (200 μg/m^3). For the COPD meta-analysis, the relevant female control group was assumed to be using a mixture of gas and chimney stoves (an estimated $PM_{2.5}$ exposure of 100 μg/m^3). The $PM_{2.5}$ exposure for males was estimated to be 65% of that for females (65 μg/m^3). For LC, the female control group was assumed to be using only gas stoves with an estimated $PM_{2.5}$ exposure of 70 μg/m^3. For males, the exposure was again assumed to be 65% of females, resulting in an equivalent exposure of 45.5 μg/m^3. The meta-analytic summary risk estimate for male COPD incidence in association with HAP $PM_{2.5}$ was 1.90 (95% CI: 1.56, 2.32) and for females was 2.70 (95% CI: 1.95, 3.75). For LC incidence among males, the summary risk estimate was 1.26 (95% CI: 1.04, 1.52) and among females was 1.81 (95% CI: 1.07, 3.06).

The lower exposure estimates in the HAP studies are substantially higher than counterfactual exposure due to the nearby use of less clean fuels; therefore, these RRs are not directly comparable to those obtained from AAP, SHS, or AS types compared with either the counterfactual (i.e., AAP) or a 0-μg/m^3 exposure (i.e., SHS, AS). This information was included in the curve-fitting process by equating the observed RRs to the ratio of the IER model evaluated at the respective two $PM_{2.5}$ concentrations.

The HAP studies estimated effects on incidence rather than mortality. For building the IER, we assumed that the RRs of mortality and incidence are equal.

Age-modification risk models for IHD and stroke mortality. Epidemiologic studies of risk factors for both IHD and stroke indicate that the RR declines with the logarithm of age, reaching 1 between 100 and 120 years of age (Singh et al. 2013). We thus modified the type-specific RR for both IHD and stroke mortality using a linear regression model of the logarithm of the median age at death for each study with the intercept equal to 1 at 110 years of age. The slope of the regression line was estimated from a meta-analysis of several risk factors (Singh et al. 2013). We applied this age-modification to the RRs and fit the IER model for each age group separately.

Selecting the counterfactual exposure. For each risk factor examined in the GBD 2010 project (Lim et al. 2012), the distribution of exposure was compared with an alternative (counterfactual) distribution termed the theoretical-minimum-risk exposure distribution (TMRED). For AAP, zero exposure is not a practical counterfactual level because it is impossible to achieve even in pristine environments (Brauer et al. 2012). Furthermore, the lowest level of exposure to $PM_{2.5}$ that is deemed beneficial has not been clearly identified. Defining the TMRED was based on two criteria (Lim et al. 2012): *a*) the availability of convincing evidence from epidemiologic studies that support a continuous reduction in risk of disease to the chosen distribution, and *b*) a distribution that is theoretically possible at the population level.

Lim et al. (2012) suggested that a positive counterfactual concentration be used. Their counterfactual concentration is bounded by the minimum concentrations observed in the studies used to estimate risk and some low percentile of the $PM_{2.5}$ distribution. There is clearly no evidence of an association below observed levels, and it is impractical to estimate the shape of the curve at the extremes of the exposure distribution. Lim et al. (2012) suggested that the fifth percentile be used and that the lower and upper bounds on the counterfactual concentration be determined by the corresponding minimum and fifth percentiles, respectively, of the AAP $PM_{2.5}$ exposure distribution for the CPS II cohort (Krewski et al. 2009), the largest cohort study of air pollution. The minimum was 5.8 μg/m^3 and the fifth percentile was 8.8 μg/m^3. Uncertainty in the counterfactual concentration was modeled as a uniform distribution between the minimum and fifth percentile.

Estimation of PAF. We estimated the PAF associated with ambient $PM_{2.5}$ exposure for all 187 countries separately for 2005. We first estimated surface $PM_{2.5}$ concentrations on a 0.1° × 0.1° grid for the globe using a combination of remote sensing and atmospheric models calibrated to ground monitoring data (Brauer et al. 2012). For each grid cell within a given country, we estimated the RR based on the IER model at the estimated $PM_{2.5}$ concentration. We then constructed a population-weighted average RR for each country using the corresponding population count 0.1° × 0.1° grid cell (Brauer et al. 2012). Both the gridded $PM_{2.5}$ and population values can be obtained from Brauer et al. (2012). The country-specific PAF = 1 – 1/WRR_{IER}, where WRR_{IER} is the population-weighted average of the RR_{IER} values at each $PM_{2.5}$ grid cell within the country.

IER model for ALRI. Mehta et al. (2013) reviewed the evidence for an association between exposure to ambient $PM_{2.5}$ and ALRI. Four cohort studies were deemed appropriate to include in an IER model (Mehta et al. 2013). We included 23 studies of parental SHS and ALRI reported by the Office on Smoking and Health (2006) with each study-specific odds ratio (OR) assigned a $PM_{2.5}$-equivalent ambient exposure of 50 μg/m^3, assuming a moderate-to-high level of exposure. Smith et al. (2011) examined the relationship between exposure to carbon monoxide (CO) from the burning of solid biomass for heating and cooking and the incidence of ALRI in Guatemala and reported incidence rates by decile average of CO personal exposures. These decile CO averages were converted to $PM_{2.5}$ concentrations using the following equation:

$$PM_{2.5}(\mathrm{mg/m^{-3}}) = 0.10(0.093, 0.12) \times CO(\mathrm{mg/m^{-3}}) + 0.067\ (0.0069, 0.13), \quad [2]$$

with 95% CIs displayed in parenthesis (Northcross et al. 2010). This equation had good predictive power (R^2 = 0.76).

Incidence rates, $I(z_i)$, corresponding to the 10 decile values of $PM_{2.5}$, denoted by z_i for 1 = 1,…10, can be compared with the risk model by taking the ratio of incidence rates for all unique pairs of $PM_{2.5}$ deciles, a total of 45 pairs, and equating them to the ratio of the corresponding risk model evaluated at the appropriate decile average. That is,

$$\begin{aligned} RR_{\mathrm{ALRI}}(z_i, z_j) &= I(z_i)/I(z_j) \\ &= [1 + \alpha\{1 - \exp[-\gamma(z_i - z_{cf})^{\delta}]\}] \\ &\quad \div [1 + \alpha\{1 - \exp[-\gamma(z_j - z_{cf})^{\delta}]\}] \quad [3] \end{aligned}$$

for all 45 unique pairs of concentrations (z_i, z_j), $\forall i > j$ = 1,…10. The 45 incidence rate ratios were combined with the 4 AAP cohort study ORs and the 23 SHS ORs in order to fit the IER model for ALRI. We assumed the same counterfactual uncertainty distribution as with the mortality IER models.

Results

The average of the RR_{IER} predictions among the simulations are displayed for the four causes of death in Figure 1 in addition to the 95% CI and the type-specific RR estimates and corresponding 95% CIs used to fit the curves. The HAP RRs for COPD and LC are presented for males and females in Figure 1 as pink-shaded boxes with the height of each box representing the uncertainty in the RR estimates and the width representing the exposure contrast at which the RRs was assumed to pertain. Each box is centered at the RR estimate and the midpoint of the two exposure values. This alternate depiction of the HAP information was necessary because the lowest exposure levels were substantially higher than the counterfactual

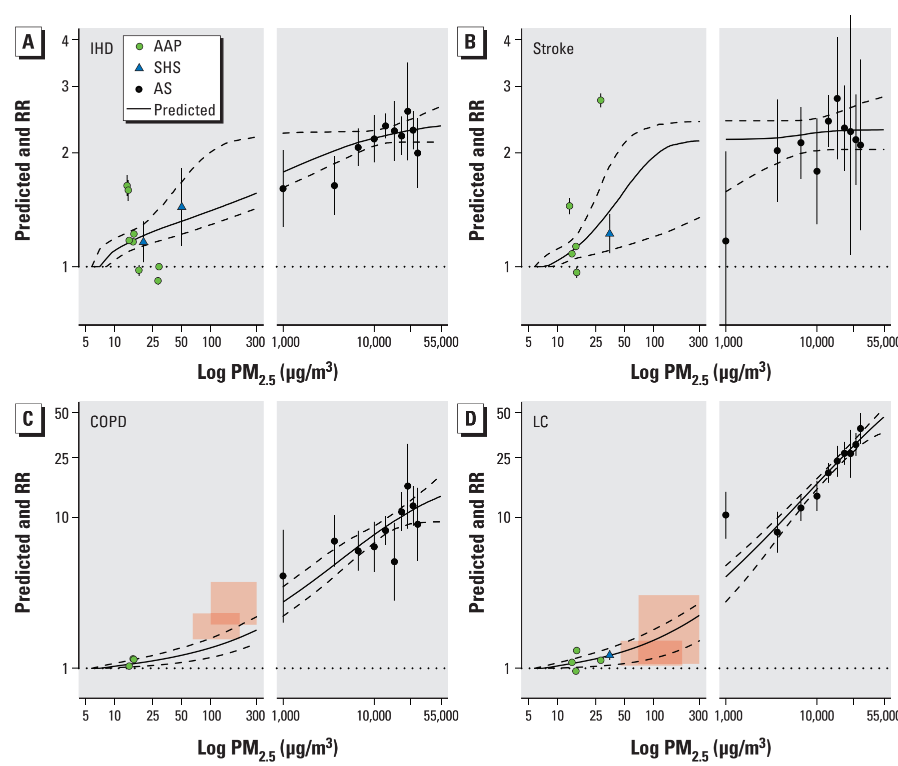


Figure 1. Predicted values of IER model (solid line) and 95% CIs (dashed line) and type-specific RRs (points) and 95% CIs (error bars) for IHD (*A*), stroke (*B*), COPD (*C*), and LC (*D*) mortality. Shaded boxes for COPD and LC mortality represent uncertainty (height) and exposure contrast (width) of RR HAP estimates for males (smaller boxes) and females (larger boxes) separately.

exposure and, therefore, not directly comparable to the RRs from the other sources. The pooled estimate of RR and its corresponding CI for SHS is displayed in placed of the study-specific SHS RRs for each unique $PM_{2.5}$ value because the study-specific RRs and CI could not be visually distinguished. Results are presented similarly for ALRI in Figure 2. In addition to the RR, the incidence of ALRI is also displayed on the right-hand *y*-axis.

The RR_{IER} function fits well the RRs for all types of $PM_{2.5}$ and causes of mortality, except for COPD and HAP, in which the IER model underestimates the observed RRs (Figure 1). This may be due to the use of the ratio of incidence rates rather than RR based on mortality data for this outcome. However, the IER curve fits the LC incidence data reasonably well. The time between diagnosis of COPD and mortality is much longer than that for LC, and thus the LC incidence data may better reflect mortality patterns than the COPD incidence data.

We compared the country-specific estimated PAFs using the age-modified models to those models using age-independent data. Age-modified RR_{IER} curves are displayed for IHD and stroke mortality in Supplemental Material, Figure S15 (top panels), with generally decreasing risk with increasing age. The country-specific PAFs based on risk models not modified by age and those in which age-modification models were used for both IHD and stroke mortality are presented in Supplemental Material, Figure S15 (bottom panels). Incorporating age-modification risk models tends to slightly decrease the PAF estimates.

The distribution of population-weighted country-average $PM_{2.5}$ concentrations and PAFs are displayed in Figure 3. The country average $PM_{2.5}$ concentrations ranged from 2–70 μg/m^3 for 2005 (Figure 3A), whereas the country-level PAFs were < 0.4 for ALRI, IHD, and stroke and < 0.25 for LC and 0.2 for COPD (Figure 3B).

Plots similar to Figures 1 and 2 are displayed for the other seven model forms examined in Supplemental Material, Figures S1–S14 for both the four causes of death (Figures S1–S7) and ALRI (Figures S8–S14). In addition, both the AICs and BICs are given in Supplemental Material, Table S2, for all eight models and five outcomes. The IER model was a better predictor of the type-specific RRs than the other seven models examined for ALRI and three of the

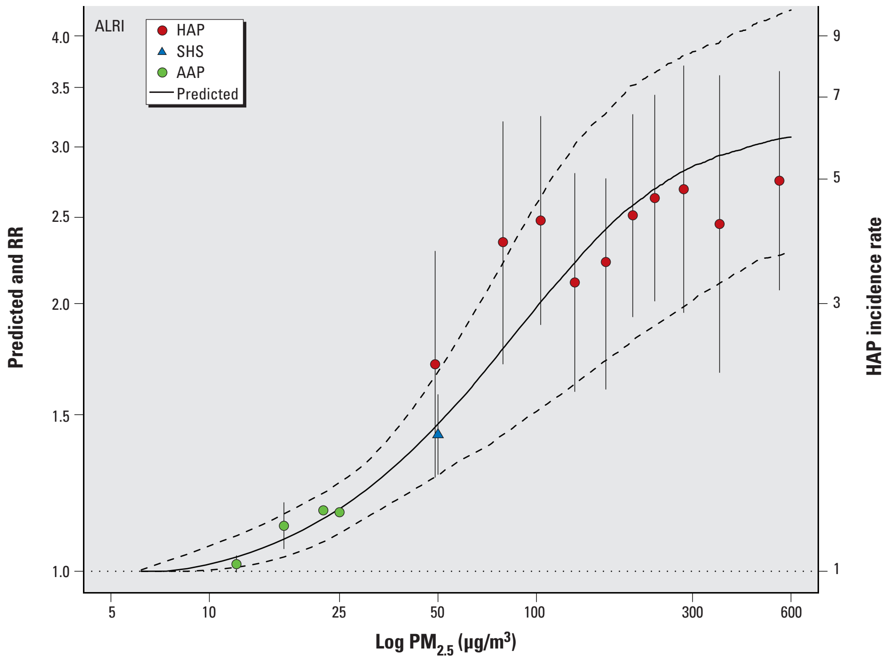


Figure 2. Predicted values of IER model (solid line) and 95% CIs (dashed line) and type-specific RRs (points) and 95% CIs (error bars) for ALRI in infants.

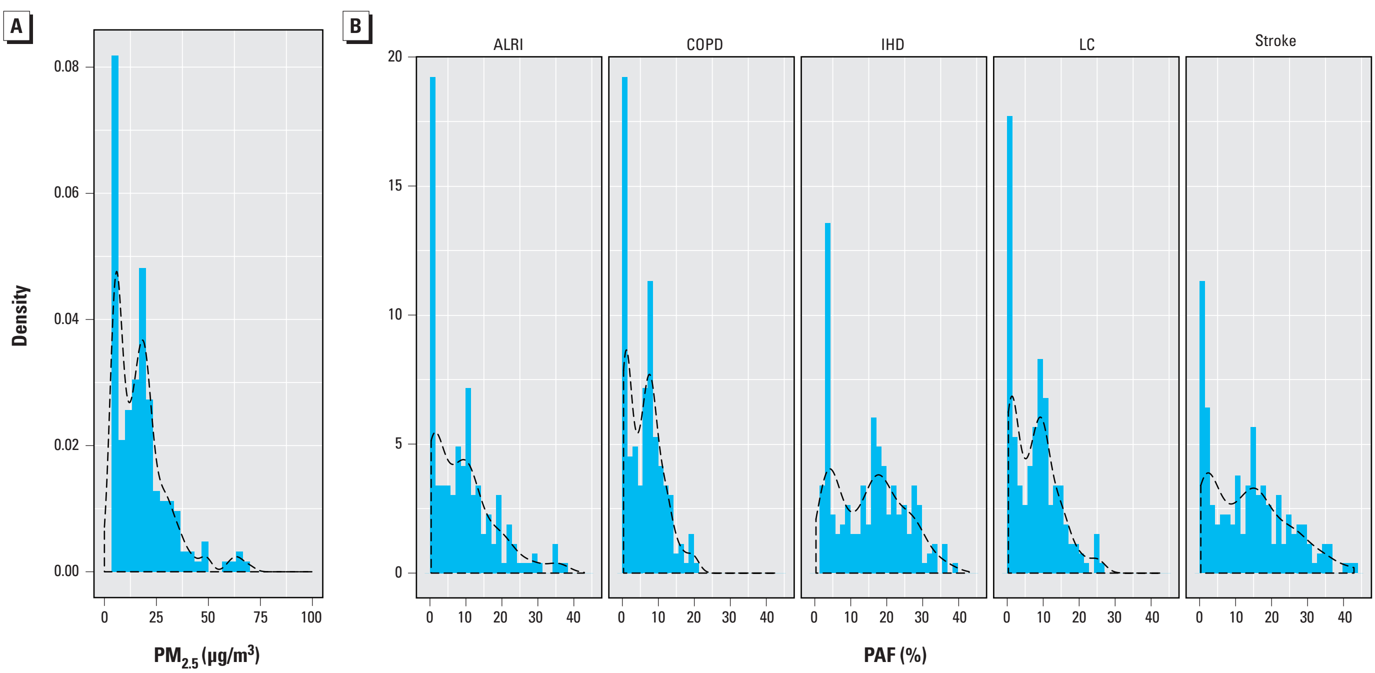


Figure 3. Density plots of country-specific, population-weighted $PM_{2.5}$ concentrations (μg/m^3) (*A*) and PAFs (*B*) by risk model and health outcome. Dashed lines represent smooth fit of density function.

four causes of death. For COPD mortality, the Power model provided a better fit than the IER model on the basis of lower AIC and BIC values (see Supplemental Material, Table S2). This was likely due to the better prediction of the HAP RR, for which the IER model clearly underestimated the RR. Graphical comparisons of the predicted values to the type-specific RRs in Supplemental Material, Figures S1–S14, verify the conclusions drawn from the AIC/BIC results.

Discussion

Exposure to $PM_{2.5}$ in ambient air has been linked to an increased risk of death from chronic cardiovascular and respiratory disease and LC in cohort studies in the United States and Europe (Chen et al. 2008; U.S. EPA 2009). Unfortunately, few long-term cohort studies have been reported for these diseases in other regions such as East and South Asia and the Middle East, where ambient exposures are much higher and where the relative contribution of specific sources of air pollution differ from those in North America and Europe (Brauer et al. 2012; Heath Effects Institute 2010).

To derive the shape of the exposure–response curve at higher ambient concentrations, we incorporated information on risk due to exposure to SHS, HAP, and AS in order to extend the risk estimates to higher exposures. The IER model combines information on mortality RR from separate types of combustion, unified by equating the delivered dose from all types in terms of equivalent ambient $PM_{2.5}$ exposures. Although we assumed that the toxicity of $PM_{2.5}$ exposure, as characterized by RR, changes with the magnitude of exposure, we also assumed that at any fixed exposure level, toxicity is roughly equivalent among all types and temporal patterns of $PM_{2.5}$ exposure. These are important assumptions because estimated $PM_{2.5}$ exposure throughout the world, whether from ambient origin or household indoor combustion, has not been differentiated by the components or sources of fine particulate matter.

Only evidence from multiple epidemiologic studies of long-term exposure to $PM_{2.5}$ in highly polluted settings can provide definitive estimates of the shape of the exposure–response function for mortality from chronic cardiovascular and respiratory diseases. However, these are starting to appear. For example, Cao et al. (2011) reported an increased risk of mortality from cardiovascular and respiratory disease and LC associated with long-term exposure to total suspended particulates (TSPs) in 71,000 residents of 31 Chinese cities. Their study offers an opportunity to assess the ability of our RR_{IER} model to estimate the observed RRs in situations with very high levels of outdoor air pollution. In order to estimate $PM_{2.5}$ RRs in the cohort, the authors used a 3:1 ratio to convert TSP to $PM_{2.5}$, based on current and historical Chinese data (Cao et al. 2011). Estimated $PM_{2.5}$ (converted from TSP) concentrations ranged among cities from 38 to 166 μg/m^3. Increases of 2.1% (95% CI: –0.3%, 4.6%), 3.3% (95% CI: 0.9%, 5.4%), and 3.3% (95% CI: –0.3%, 6.9%) in IHD, stroke, and LC mortality, respectively, were associated with a 10-μg/m^3 change in estimated equivalent $PM_{2.5}$ exposures in this cohort (Kan H, personal communication).

Because the cohort members did not experience exposures near the lowest concentrations applicable to our RR model (i.e., the counterfactual concentration), we cannot determine RRs estimated from the cohort and directly compare them to our RR model, which is relative to a much lower counterfactual concentration. However, we can determine RR between concentrations observed in the cohort itself. We first determined the mean of the four quartiles of $PM_{2.5}$ concentrations as 40, 91, 106, and 127 μg/m^3, respectively (Kan H, personal communication) and calculated the RR between consecutive quartile averages assuming the exponential risk model form as was used by the study authors. The geometric average of these three RRs was then determined as a summary measure of change in risk over the $PM_{2.5}$ exposure distribution. A similar calculation was undertaken for the RR_{IER} model. The RRs observed in the Chinese cohort and those predicted by RR_{IER} were similar for the three causes of death examined [IHD: China RR = 1.06 (95% CI: 0.99, 1.14) and IER RR = 1.05 (95% CI: 1.03, 1.1); stroke: China RR = 1.10 (95% CI: 1.03, 1.17) and IER RR = 1.08 (95% CI: 1.01, 1.14; LC: China RR = 1.10 (95% CI: 0.99, 1.22) and IER RR = 1.09 (95% CI: 1.06, 1.12)], suggesting that our IER model yielded reasonable predictions in the change in risk over a range of concentrations that prevail in China and other highly polluted settings that were not observed in cohort studies conducted in North America and Western Europe.

There are, however, some limitations in this comparison. First, TSP was a poorer predictor of cardiovascular mortality than $PM_{2.5}$ in U.S.-based cohort studies (Pope et al. 2002). Second, uncertainty about the temporal and spatial consistency of the TSP/$PM_{2.5}$ conversion ratio of 3:1 added uncertainty to our interpretation of the results from the Chinese cohort.

Additional uncertainties are due to a lack of information on actual exposure to $PM_{2.5}$ for some source-specific RRs used to fit the model, notably *a*) scarce information on actual exposure from SHS in the relevant epidemiologic studies (Pope et al. 2009, 2011b), which required the estimation of $PM_{2.5}$ concentrations from other studies; *b*) potential misclassification of exposure for SHS estimates due to possible co-exposure from AAP of the exposed group; and *c*) the duration of exposure, which differs when it comes to exposures from AAP, SHS, HAP, and AS—the lifetime duration of exposure in AS may be much shorter than in the other exposures and the received doses may, therefore, not be proportional to concentrations according to type of exposure. Uncertainties may be reduced by improving precision in the actual exposure estimates of the RRs from the epidemiologic literature used for developing the proposed model.

Multiple studies were used to estimate RRs associated with exposure to AAP, SHS, and HAP. For AS, we estimated RRs for active cigarette smokers from a single cohort, the CPS II. This cohort was also used in the GBD 2010 project to estimate risk specifically for AS (Lim et al. 2012). However, the pattern of the association between the number of cigarettes smoked per day and cause-specific mortality observed in the CPS-II cohort may not reflect the patterns observed in other cohort studies of AS (e.g., Pirie et al. 2013). Similarly, the IER for ALRI is fit through RR from studies of AAP and SHS conducted in a limited number of mostly high-income countries, and a single developing country RR estimate for HAP $PM_{2.5}$ exposure and ALRI (Smith et al. 2011). We thus recommend that future work on the IER function include additional sensitivity analyses of the type-specific RRs to which the curve is fit. Future work could also include the uncertainty in the estimate of $PM_{2.5}$ from CO and new information in this relationship (McCracken et al. 2013).

The key assumptions that underlie the IER, discussed above, largely serve to justify the integration of risk estimates for different types of PM exposure. These assumptions, and their tenability, have been addressed elsewhere (Pope et al. 2009, 2011a, 2011b). Unfortunately, for several of the most critical assumptions, those concerning the relative toxicity per unit mass of $PM_{2.5}$ of different types (e.g., AAP and AS), not accounting for the temporal pattern of exposure, and the absence of interaction among types of combustion, there is little empirical evidence against which to evaluate those assumptions or to evaluate in detail specific implications of their violation. Each warrants additional research.

Although we set the counterfactual concentration to be drawn from a uniform distribution with a lower bound of 5.8 μg/m^3 and an upper bound of 8.8 μg/m^3, we are not suggesting that there is convincing evidence that $PM_{2.5}$ mortality and ALRI risk is zero below any specific concentration based on biological considerations (Brook et al. 2010). Absence of such evidence from epidemiologic studies does not necessarily imply evidence of the absence of such a counterfactual concentration. We thus take the conservative approach and set a positive counterfactual concentration. However, our approach can be adapted to a different counterfactual if new evidence supporting a positive association at lower concentrations becomes available. One such piece of evidence was observed in Canada, where positive associations as low as 2 μg/m^3 were noted (Crouse et al. 2012).

The Lin50 and Log models proposed by Cohen et al. (2004) were used for the previous GBD estimates, and the Log model is currently recommended by the WHO (Ostro 2004). However, the unknown parameters in these models were estimated from a single cohort study of AAP, the CPS-II, which required analysis of the original data. The IER model uses RR estimates available in the open literature, allowing periodic updating of risk functions based on systematic review of the literature, and it does not require analyses of primary data not in the public domain. As new epidemiologic studies and evidence on type-specific $PM_{2.5}$ exposure appear, the models can be reestimated by any interested member of the scientific community using publically available information.

Conclusion

Fine particulate mass–based RR models can be developed that cover the entire global range of ambient exposure to $PM_{2.5}$ by integrating RR information from different combustion sources that generate emissions of particulate matter. The specific RR model form we identified in the present study can provide superior predictive power for leading global causes of mortality for air pollution compared with a range of alternative model forms.

References

Anenberg SC, Horowitz LW, Tong DQ, West JJ. 2010. An estimate of the global burden of anthropogenic ozone and fine particulate on premature human mortality using atmospheric modeling. Environ Health Perspect 118:1189–1195; doi:10.1289/ehp.0901220.

Balakrishnan K, Ghosh S, Ganguli B, Sambandam S, Bruce NG, Barnes DF, et al. 2013. State and national household concentrations of $PM_{2.5}$ from solid cookfuel use: results from measurements and modeling in India for estimation of the global burden of disease. Environ Health 12:77; doi:10.1186/1476-069X-12-77.

Brauer M, Amann M, Burnett RT, Cohen A, Denterner F, Ezzati M, et al. 2012. Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution. Environ Sci Technol 46:652–660.

Brook RD, Rajagopalan, S, Pope CA III, Brook JR, Bhatnagar A, Diez-Roux A, et al. 2010. Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association. Circulation 121:2331–2378.

Cao J, Yang C, Li J, Chen R, Chen B, Gua D, Kan H. 2011. Association between long-term exposure to outdoor air pollution and mortality in China: a cohort study. J. Hazard Mater 186:1594–1600.

Chen H, Goldberg MS, Villeneuve PJ. 2008. A systematic review of relation between long-term exposure to ambient air pollution and chronic disease. Rev Environ Health 23:243–296.

Cohen A, Anderson HR, Ostro B, Pandey K, Krzyzanowski M, Kunzli N, et al. 2004. Urban air pollution. In: Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors (Ezzati M, Lopez A, Rodgers A, Murray CJL, eds). Geneva:World Health Organization, 1353–1433.

Committee on the Medical Effects of Air Pollutants. 2009. Long-Term Exposure to Air Pollution: Effect on Mortality. A Report by the Committee on the Medical Effects of Air Pollutants. Chilton, Oxfordshire, UK:Health Protection Agency. Available: http://www.comeap.org.uk/images/stories/Documents/Reports/mortality%20report%202009.pdf [accessed 6 March 2014].

Cooke RM, Wilson AM, Tuomisto JT, Morales O, Tainio M, Evans JS. 2007. A probabilistic characterization of the relationship between fine particulate matter and mortality: elicitation of European experts. Environ Sci Technol 41:6598–6605.

Crouse DL, Peters PA, van Donkelaar A, Goldberg MS, Villeneuve PJ, Brion O, et al. 2012. Risk of nonaccidental and cardiovascular mortality in relation to long-term exposure to low concentrations of fine particulate matter: a Canadian national-level cohort study. Environ Health Perspect 120:708–714; doi:10.1289/ehp.1104049.

Evans J, van Donkelaar A, Martin RV, Burnett R, Rainham DG, Birkett NJ, et al. 2013. Estimates of global mortality attributable to particulate air pollution using satellite imagery. Environ Res 120:33–42.

Health Effects Institute, International Scientific Oversight Committee). 2010. Outdoor Air Pollution and Health in the Developing Countries of Asia: A Comprehensive Review. Special Report 18. Boston, MA:Health Effects Institute. Available: http://pubs.healtheffects.org/getfile.php?u=602 [accessed 6 March 2014].

Krewski D, Jerrett M, Burnett RT, Ma R, Hughes E, Shi Y, et al. 2009. Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality. HEI Research Report 140. Boston, MA:Health Effects Institute. Available: http://pubs.healtheffects.org/getfile.php?u=478 [accessed 6 March 2014].

Lim SS, Vos T, Flaxman AD, Danaei G, Shibaya K, Adair-Rahani H, et al. 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet 380:2224–2260.

McCracken JP, Schwartz J, Diaz A, Bruce N, Smith KR. 2013. Longitudinal Relationship between Personal CO and Personal $PM_{2.5}$ among Women Cooking with Woodfired Cookstoves in Guatemala. PLoS ONE 8(2):e55670; doi:10.1371/journal.pone.0055670.

Mehta S, Shin H, Burnett R, North T, Cohen AJ. 2013. Ambient particulate air pollution and acute lower respiratory infections: a systematic review and implications for estimating the global burden of disease. Air Qual Atmos Health 6:69–83.

Northcross A, Chowdhury Z, McCracken J, Canuzc E, Smith KR. 2010. Estimating personal PM2.5 exposures using CO measurements in Guatemalan households cooking with wood fuel. J Environ Monit 12:873–878.

Office on Smoking and Health. 2006. The Health Consequences of Involuntary Exposure to Tobacco Smoke: A Report of the Surgeon General. Atlanta, GA:Centers for Disease Control and Prevention. Available: http://www.ncbi.nlm.nih.gov/books/NBK44324/ [accessed 28 February 2014].

Oono IP, Mackay DF, Pell JP. 2011. Meta-analysis of the association between secondhand smoke exposure and stroke. J Public Health (Oxf) 33:496–502.

Ostro B. 2004. Outdoor Air Pollution: Assessing the Environmental Burden of Disease at National and Local Levels. Environmental Burden of Disease Series, No. 5 (Prüss-Üstün A, Campbell-Lendrum, D, Corvalán C, Woodward A, eds). Geneva:World Health Organization. Available: http://www.who.int/quantifying_ehimpacts/publications/ebd5.pdf [accessed 6 March 2014].

Pirie K, Peto R, Reeves GK, Green J, Beral V, Million Women Study Collaborators. 2013. The 21st century hazards of smoking and benefits of stopping: a prospective study of one million women in the UK. Lancet 381:133–141.

Pope CA III, Brook RD, Burnett RT, Dockery DW. 2011a. How is cardiovascular disease mortality risk affected by duration and intensity of fine particulate matter exposure? An integration of the epidemiologic evidence. Air Qual Atmos Health 4:5–14.

Pope CA III, Burnett RT, Krewski D, Jerrett M, Shi Y, Calle EE, et al. 2009. Cardiovascular mortality and exposure to fine particulate matter from air pollution and cigarette smoke: shape of the exposure-response relationship. Circulation 120:941–948.

Pope CA III, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, et al. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 278:1132–1141.

Pope CA III, Burnett RT, Turner MC, Cohen A, Krewski D, Jerrett M, et al. 2011b. Lung cancer and cardiovascular disease mortality associated with particulate matter exposure from ambient air pollution and cigarette smoke: shape of the exposure–response relationships. Environ Health Perspect 119:1616–1621; doi:10.1289/ehp.1103639.

Singh GM, Danaei G, Farzadfar F, Stevens GA, Woodward M, Wormser D, et al. 2013. The age-specific quantitative effects of metabolic risk factors on cardiovascular diseases and diabetes: a pooled analysis. PLoS One 8:e65174; doi:10.1371/journal.pone.0065174.

Smith KR. 1987. Biofuels, Air Pollution, and Health: A Global Review. New York:Plenum Publishing.

Smith KR, Bruce N, Balakrishnan K, Adair-Rohani H, Balmes J, Chafe Z, et al. 2014. Millions dead: how do we know and what does it mean? Methods used in the Comparative Risk Assessment of Household Air Pollution. Ann Rev Public Health 35:27.1–27.23.

Smith KR, McCracken JP, Weber MW, Hubbard A, Jenny A, Thompso LM, et al. 2011. Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial. Lancet 378:1717–1726.

Stanek LW, Sacks JD, Dutton SJ, Dubois JJ B. 2011. Attributing health effects to apportioned components and sources of particulate matter: an evaluation of collective results. Atmos Environ 45:5655–5663.

U.S. EPA (U.S. Environmental Protection Agency). 2009. Integrated Science Assessment for Particulate Matter. EPA/600/R-08/139F. Research Triangle Park, NC:U.S. EPA. Available: http://www.epa.gov/ncea/pdfs/partmatt/Dec2009/PM_ISA_full.pdf [accessed 6 March 2014].

WHO (World Health Organization, Regional Office for Europe). 2006. Air Quality Guidelines—Global Update 2005. Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. Copenhagen:WHO Regional Office for Europe. Available: http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf [accessed 6 March 2014].

WHO (World Health Organization, Regional Office for Europe). 2007. Health Relevance of Particulate Matter from Various Sources. Copenhagen:WHO Regional Office for Europe. Available: http://www.euro.who.int/__data/assets/pdf_file/0007/78658/E90672.pdf [accessed 6 March 2014].

Erratum: "An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure"

In "An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure" by Burnett et al. [Environ Health Perspect 122:397–403 (2014); http://dx.doi.org/10.1289/ehp.1307049], the authors omitted a reference. Balakrishnan et al. (2013) should have been cited in the first paragraph of "Methods" for HAP (household air pollutants). The correct sentence and reference are provided below.

> The equivalent long-term $PM_{2.5}$ exposure from HAP was estimated for study subjects using coal or biomass for cooking (Balakrishnan et al. 2013) and for those study subjects using cleaner fuels to integrate this information into our IER risk model.

Balakrishnan K, Ghosh S, Ganguli B, Sambandam S, Bruce NG, Barnes DF, et al. 2013. State and national household concentrations of $PM_{2.5}$ from solid cookfuel use: results from measurements and modeling in India for estimation of the global burden of disease. Environ Health 12:77; doi:10.1186/1476-069X-12-77.

The authors regret the error.

Changes in Residential Proximity to Road Traffic and the Risk of Death From Coronary Heart Disease

Wen Qi Gan,[a] Lillian Tamburic,[b] Hugh W. Davies,[a] Paul A. Demers,[a,c] Mieke Koehoorn,[a,c] and Michael Brauer[a]

Background: Residential proximity to road traffic is associated with increased coronary heart disease (CHD) morbidity and mortality. It is unknown, however, whether changes in residential proximity to traffic could alter the risk of CHD mortality.

Methods: We used a population-based cohort study with a 5-year exposure period and a 4-year follow-up period to explore the association between changes in residential proximity to road traffic and the risk of CHD mortality. The cohort comprised all residents aged 45–85 years who resided in metropolitan Vancouver during the exposure period and without known CHD at baseline (n = 450,283). Residential proximity to traffic was estimated using a geographic information system. CHD deaths during the follow-up period were identified using provincial death registration database. The data were analyzed using logistic regression.

Results: Compared with the subjects consistently living away from road traffic (>150 m from a highway or >50 m from a major road) during the 9-year study period, those consistently living close to traffic (≤150 m from a highway or ≤50 m from a major road) had the greatest risk of CHD mortality (relative risk [RR] = 1.29 [95% confidence interval = 1.18–1.41]). By comparison, those who moved closer to traffic during the exposure period had less increased risk than those who were consistently exposed (1.20 [1.00–1.43]), and those who moved away from traffic had even less increase in the risk (1.14 [0.95–1.37]). All analyses were adjusted for baseline age, sex, pre-existing comorbidities (diabetes, chronic obstructive pulmonary disease, hypertensive heart disease), and neighborhood socioeconomic status.

Conclusions: Living close to major roadways was associated with increased risk of coronary mortality, whereas moving away from major roadways was associated with decreased risk.

(*Epidemiology* 2010;21: 000–000)

A growing body of epidemiologic evidence has demonstrated that long-term exposure to ambient air pollution, especially fine particles, is associated with increased cardiovascular morbidity and mortality.[1,2] Several cohort studies suggest that coronary heart disease (CHD) is more strongly associated with fine particulate air pollution than are other cardiovascular outcomes.[3,4] In metropolitan areas, road traffic is a major contributor to air pollution.[5,6] A European study estimated that approximately half of the adult mortality from air pollution was attributed to traffic-related air pollution.[7] Because exposure to traffic-related air pollution is extensive worldwide, the corresponding adverse cardiovascular effects may represent an important public health problem.[1]

The concentrations of traffic-related air pollutants decrease exponentially from major roadways and typically approach background concentrations within about 150 meters.[6,8] The distances from residences to major roadways may therefore reflect spatial variability in the concentrations of traffic-related air pollutants. Although traffic proximity may also be associated with other exposures such as traffic noise, it can serve as a simple and policy-relevant surrogate for exposure to traffic-related air pollution.[9,10] This metric has been widely used in epidemiologic studies of the health effects of traffic-related air pollution.[9–19]

There have been a number of epidemiologic studies examining the associations between residential proximity to traffic and adverse cardiovascular outcomes including arterial atherosclerosis[11,12] and CHD morbidity and mortality.[13–19] Although most of these studies have reported associations, the findings are not entirely consistent. One critical limitation of these studies is the assumption that baseline residential exposure status is consistent during the entire follow-up period; residential relocation after baseline enrollment has generally been ignored. This unrealistic assumption may

Submitted 30 September 2009; accepted 23 January 2010.
From the [a]School of Environmental Health, The University of British Columbia, Vancouver, BC, Canada; [b]Centre for Health Services and Policy Research, The University of British Columbia, Vancouver, BC, Canada; and [c]School of Population and Public Health, The University of British Columbia, Vancouver, BC, Canada.
Supported (in part) by Health Canada via an agreement with the British Columbia Centre for Disease Control to the Border Air Quality Study; the Center for Health and Environment Research at The University of British Columbia, supported by the Michael Smith Foundation for Health Research; the Canadian Institutes of Health Research Frederick Banting and Charles Best Canada Graduate Scholarship and by the Michael Smith Foundation for Health Research Senior Graduate Studentship (to W.G.); and a Michael Smith Foundation for Health Research Senior Scholar Award (to M.K.).
SDC Supplemental digital content is available through direct URL citations in the HTML and PDF versions of this article (www.epidem.com).
Correspondence: Michael Brauer, School of Environmental Health, The University of British Columbia, 366A–2206 East Mall, Vancouver, BC, Canada V6T 1Z3. E-mail: brauer@interchange.ubc.ca.

ISSN: 1044-3983/10/2105-0001
DOI: 10.1097/EDE.0b013e3181e89f19

result in exposure misclassification, and thus bias effect estimates toward the null.

We conducted a large population-based cohort study with detailed residential history information to investigate the association between residential proximity to road traffic and the risk of CHD mortality. Specifically, we examined the following factors: (1) whether residential proximity to traffic was associated with higher levels of exposure to traffic-related air pollution; (2) whether living close to traffic was associated with an increased risk of CHD mortality; and (3) whether changing residences, and therefore changing proximity to traffic, was associated with an altered risk of CHD mortality.

METHODS

Study Design

This population-based cohort study was conducted in metropolitan Vancouver, Canada. We used linked administrative databases from British Columbia's universal health insurance system to assemble a population-based cohort (eAppendix, http://links.lww.com/EDE/A405). This study included 2 stages: a 5-year exposure period (January 1994–December 1998), and a 4-year follow-up period (January 1999–December 2002). Mortality information during the follow-up period was identified from the provincial death registration database. CHD mortality was compared between study subjects with different residential-traffic-exposure profiles to determine the relationship between residential proximity to road traffic and the risk of CHD mortality. This study was approved by the institutional review board of The University of British Columbia.

Study Cohort

All metropolitan Vancouver residents who met the following criteria at baseline (January 1999) were included in the cohort: (1) registered with the provincial health insurance plan, which provides universal coverage to the resident population; (2) age 45–85 years; and (3) without previous diagnosis of CHD. A small number (4%) of study subjects who moved to other regions of the province during the 5-year exposure period were included, all other subjects remained in the study region during the exposure period.

Residential Proximity to Road Traffic

We categorized residential proximity to traffic based on individual residential histories (eAppendix, http://links.lww.com/EDE/A405), and whether a 6-digit residential postal code (area centroid) was located within 50 m or 150 m of a highway or a major road during the 5-year exposure period and the 4-year follow-up period. The study subjects were divided into 4 groups:

1. Not exposed to traffic: consistently living away from traffic until the end of follow-up;
2. Consistent exposure to traffic: consistently living close to traffic until the end of follow-up;
3. Moved close to traffic: changing residence from nonexposed to exposed to traffic during the exposure period and retaining this exposure status until the end of follow-up;
4. Moved away from traffic: changing residence from exposed to nonexposed to traffic during the exposure period and retaining this nonexposure status until the end of follow-up.

Subjects with more than one change in exposure status during the exposure period were excluded; those who changed their exposure status during the follow-up period were also excluded.

Depending on road types (highway or major road) and distance from major roadways, residential proximity to traffic was divided into 5 categories: (1) ≤50 versus >50 m from a highway; (2) ≤150 versus >150 m from a highway; (3) ≤50 versus >50 m from a major road; (4) ≤150 versus >150 m from a major road; (5) ≤150 m from a highway or ≤50 m from a major road versus >150 m from a highway or >50 m from a major road. Subjects living within a specific distance were assigned to the exposure group, while the rest were assigned to the nonexposure group (eAppendix, http://links.lww.com/EDE/A405).

Traffic-related Air Pollution Assessment

We used high-resolution land-use regression models to evaluate exposure levels to traffic-related air pollutants. Because the air pollution measurements did not cover the whole study region, air pollution data were available only for a subgroup of the cohort.

Using detailed residential history and corresponding monthly concentrations of traffic-related air pollutants during the 5-year exposure period, average concentrations of air pollutants were calculated for each subject. Detailed methods for the measurement of air pollutants in this study have been described elsewhere.[20,21] A brief description of traffic-related air pollution assessment is available in the eAppendix (http://links.lww.com/EDE/A405).

Coronary Heart Disease Mortality

A case of CHD death was defined as a death record in the provincial death registration database with CHD (ICD-9 codes 410–414, 429.2 and ICD-10 codes I20–I25) as the cause of death. A small proportion of deaths were identified using provincial hospitalization records: a hospitalization death record with CHD as the principal diagnosis for a hospital admission.

Subjects who had a hospitalization record with CHD as the principal or primary diagnosis before baseline (on the basis of data available from January 1991 to December 1998) were regarded as previously-diagnosed CHD cases, and were excluded from the analysis.

Pre-existing Comorbidities

Chronic obstructive pulmonary disease (COPD)[22] (ICD-9: 490, 491, 492, 496; ICD-10: J40–J44), diabetes[23] (ICD-9, 250; ICD-10, E10–E14), and hypertensive heart disease[23] (ICD-9: 401–404; ICD-10: I10–I14) are independent risk factors for CHD. In addition, these chronic diseases and CHD share common behavioral risk factors such as cigarette smoking. In an effort to control the influence of the pre-existing comorbidities and these common behavioral risk factors, all diagnoses (not restricted to principal or primary diagnosis) in a hospitalization record were used to identify subjects with these comorbidities. One hospitalization record with the diagnosis of any of these diseases during January 1991 to December 1998 was defined as the presence of pre-existing comorbidities.

Neighborhood Socioeconomic Status

Individual-level income data were not available in this study. We used neighborhood-income quintiles from the 2001 Statistics Canada Census data to approximate a subject's socioeconomic status (SES). Neighborhood-income quintiles were assigned to study subjects through their residential postal codes (eAppendix, http://links.lww.com/EDE/A405).

Statistical Analysis

We compared the baseline characteristics among the exposure groups using a χ^2 test for dichotomous variables, one-way analysis of variance (ANOVA) for continuous variables, and Tukey's post hoc analysis for pair-wise comparisons of continuous variables. Similarly, in a subgroup analysis for the subjects with air pollution data, we used ANOVA and Tukey's post hoc analysis to determine whether residential traffic-exposure profiles were associated with exposure levels to traffic-related air pollutants.

To determine the association between residential proximity to traffic (predictor variable) and the risk of CHD mortality (dependent variable), we first performed bivariable logistic regression analysis using the nonexposed group as the reference category. Then we performed multivariable logistic regression analysis to adjust for age (quintiles), sex, neighborhood income (quintiles), and pre-existing comorbidities including diabetes, COPD, or hypertensive heart disease (yes or no). These analyses were repeated for different combinations of road types (highway or major road) and distances (50 or 150 m).

To examine the influence of age and sex on the risk of CHD mortality associated with traffic exposure, we performed stratification analyses by age (<65 years, ≥65 years) and sex, using the exposure category ≤150 m from a highway or ≤50 m from a major road.

The exposure category "≤50 versus >50 m from a highway" had the largest effect estimates. We therefore used this category to perform a sensitivity analysis in which we compared the relative risks of CHD mortality using various distances from a highway and various frames of reference.

All analyses were performed using SAS 9.1 (SAS Institute Inc., Cary, NC).

RESULTS

We use the road traffic exposure category "≤150 m from a highway or ≤50 m from a major road versus >150 m from a highway or >50 m from a major road" to present the overall results of this study. At baseline in January 1999, there were 488,785 subjects who met the inclusion criteria. At the end of follow-up, 38,502 persons (8%) were lost to follow-up, mainly due to moving out of the province or dying from other diseases. This left 450,283 subjects with complete data; 210,128 persons (47%) changed their residences at least one time during the 9-year study period, and 68,726 persons (15%) changed their exposure status. We excluded 12,619 persons (3%) with multiple changes in exposure status and 22,871 (5%) who changed their exposure status during the follow-up period. This left 414,793 subjects for analysis: 328,609 (79%) who consistently lived away from traffic, 52,948 (13%) who consistently lived close to traffic, 15,747 (4%) who moved close to traffic, and 17,489 (4%) who moved away from traffic (Table 1).

The baseline characteristics of these subjects are summarized by the 4 exposure groups in Table 1. Fewer than half (46%) of the subjects were male; the average age (SD) was 59 (11) years (range, 45–83 years). Overall, compared with those consistently living away from traffic, persons who consistently lived close to traffic were older and more likely to have lower neighborhood SES and pre-existing comorbidities.

Based on the land-use regression data that incorporated high spatial resolution, persons who consistently lived close to traffic were exposed to elevated concentrations of black carbon, $PM_{2.5}$, NO_2, and NO during the 5-year exposure period (Table 2). Furthermore, those once living close to traffic were also exposed to higher concentrations of black carbon, NO_2, and NO; this increment was even larger for those who moved their residences close to traffic.

During the follow-up period, 3133 people (3097 from the death registration database and 36 from hospitalization records) died of CHD, for an overall mortality rate of 7.6 per 1000 subjects. Compared with subjects consistently living away from traffic, those consistently living close to traffic were 69% (95% confidence interval [CI] = 1.55–1.85) more likely to die of CHD during the follow-up period. For those who moved away from traffic during the exposure period, there was a 4% increase in the risk of CHD mortality (0.87–1.25) during the follow-up period compared with the unexposed. For those moving closer to traffic during the exposure period, the risk of CHD mortality increased 23% (1.03–1.46) as compared with the unexposed. Adjustment for

TABLE 1. Baseline Characteristics[a] of Study Subjects by Exposure Groups[b]

	Not Exposed to Traffic (n = 328,609)	Moved Close to Traffic (n = 15,747)	Moved Away From Traffic (n = 17,489)	Consistent Exposure to Traffic (n = 52,948)
Men	46	46	47	45
Age (years); mean (SD)	58.7 (10.4)	58.6 (10.2)	57.6 (10.0)	61.0 (10.9)
Age quintiles (years)				
45–48	19	19	21	15
49–53	22	21	23	18
54–60	21	21	21	19
61–69	20	21	20	22
70–83	19	18	15	26
Comorbidity				
Diabetes	1.9	2.1	2.0	2.5
COPD	1.0	1.2	1.2	1.5
Hypertensive heart disease	3.7	4.0	3.9	4.6
Any of the above	5.6	6.4	6.1	7.2
Income quintiles[c]				
1	15	25	20	27
2	18	19	19	20
3	19	21	20	19
4	22	18	22	16
5	26	17	20	19

[a]Percent, unless otherwise specified.
[b]Traffic exposure was defined as ≤150 m from a highway or ≤50 m from a major road.
[c]Quintile 1 represents the lowest and Quintile 5 the highest neighborhood income quintile.

TABLE 2. Average Concentrations of Traffic-related Air Pollutants by Exposure Groups

	Not Exposed to Traffic (n = 306,296) Mean (SD)	Moved Close to Traffic (n = 13,285) Mean (SD)	Moved Away From Traffic (n = 14,582) Mean (SD)	Consistent Exposure to Traffic (n = 50,502) Mean (SD)
Black carbon (10^{-5}/m)	1.1 (0.7)	2.3 (1.1)	1.9 (0.9)	3.0 (1.5)
$PM_{2.5}$ ($\mu g/m^3$)	4.0 (1.6)	4.2 (1.6)	4.1 (1.6)	4.3 (1.8)
NO_2 ($\mu g/m^3$)	31.3 (7.9)	33.9 (7.5)	33.0 (7.6)	35.5 (7.9)
NO ($\mu g/m^3$)	28.8 (8.2)	39.5 (13.4)	34.8 (10.7)	45.9 (16.6)

This is a sub-group analysis for the subjects (93%) with land-use regression data. Traffic exposure was defined as ≤150 m from a highway or ≤50 m from a major road.

baseline age, sex, pre-existing comorbidities, and neighborhood SES generally reduced the relative risks but did not change the overall pattern of the results: the risk of CHD mortality increased by 29% (1.18–1.41), 14% (0.95–1.37), and 20% (1.00–1.43), respectively, for those consistently living close to traffic, moving away from traffic, and moving close to traffic, respectively (Table 3).

Similar CHD mortality patterns were observed when the analysis was repeated using different road types and distances (Table 3, Fig. 1). Figure 1 shows that the risk of CHD mortality was strongly dependent on road types (traffic volume) and the distances from major roadways. For example, for those consistently living close to traffic, the risk of CHD mortality rapidly decreased when the distance from traffic increased from 50 to 150 m, or when road type changed from a highway (21,000–114,000 vehicles/day) to a major road (15,000–18,000 vehicles/day). Overall, compared with consistently living away from traffic, consistently living close to traffic was associated with the highest risk of CHD mortality (Fig. 1); moving closer to traffic was associated with an increased risk but lower risk compared with consistently living close to traffic. Moving away from traffic was associated with a decreased risk but higher risk compared with consistently living away from traffic.

For those consistently living within 150 m from a highway or 50 m from a major road (vs. consistently living >150 m from a highway or >50 m from a major road), the risk of CHD mortality was higher for men than for women and higher for the younger (<65 years) than for the older group (≥65 years) (Fig. 2).

TABLE 3. Association of Road Traffic Exposure With Coronary Heart Disease Mortality

Exposure Category	Not Exposed to Traffic[a]	Moved Close to Traffic	Moved Away From Traffic	Consistent Exposure to Traffic
≤150 m Highway or ≤50 m major road				
No. deaths/total number	2271/328,609	131/15,747	124/17,489	607/52,948
Crude RR (95% CI)	1.00	1.23 (1.03–1.46)	1.04 (0.87–1.25)	1.69 (1.55–1.85)
Adjusted RR (95% CI)[b]	1.00	1.20 (1.00–1.43)	1.14 (0.95–1.37)	1.29 (1.18–1.41)
≤50 m Highway				
No. deaths/total number	3164/434,602	26/2304	21/2729	73/4343
Crude RR (95% CI)	1.00	1.55 (1.05–2.29)	1.05 (0.69–1.62)	2.33 (1.84–2.94)
Adjusted RR (95% CI)[b]	1.00	1.44 (0.97–2.13)	1.09 (0.71–1.69)	1.54 (1.21–1.96)
≤150 m Highway				
No. deaths/total number	2851/397,341	59/7016	62/8484	257/20,085
Crude RR (95% CI)	1.00	1.18 (0.91–1.53)	1.02 (0.80–1.32)	1.80 (1.59–2.05)
Adjusted RR (95% CI)[b]	1.00	1.22 (0.94–1.59)	1.11 (0.86–1.44)	1.36 (1.19–1.55)
≤50 m Major road				
No. deaths/total number	2674/370,505	90/10,534	88/12,935	330/31,073
Crude RR (95% CI)	1.00	1.20 (0.97–1.48)	0.95 (0.77–1.18)	1.49 (1.33–1.67)
Adjusted RR (95% CI)[b]	1.00	1.16 (0.93–1.43)	1.07 (0.86–1.33)	1.15 (1.02–1.29)
≤150 m Major road				
No. deaths/total number	1752/247,483	157/19,724	170/25,781	1024/112,093
Crude RR (95% CI)	1.00	1.17 (1.00–1.38)	0.97 (0.83–1.14)	1.35 (1.25–1.46)
Adjusted RR (95% CI)[b]	1.00	1.24 (1.05–1.46)	1.09 (0.93–1.28)	1.11 (1.02–1.19)

The total number of subjects in each traffic exposure category is different due to exclusion of subjects with multiple changes in exposure status and subjects who changed their exposure status during the follow-up period.

[a]Reference category.

[b]Adjusted for age, sex, neighborhood socioeconomic status, and pre-existing comorbidities.

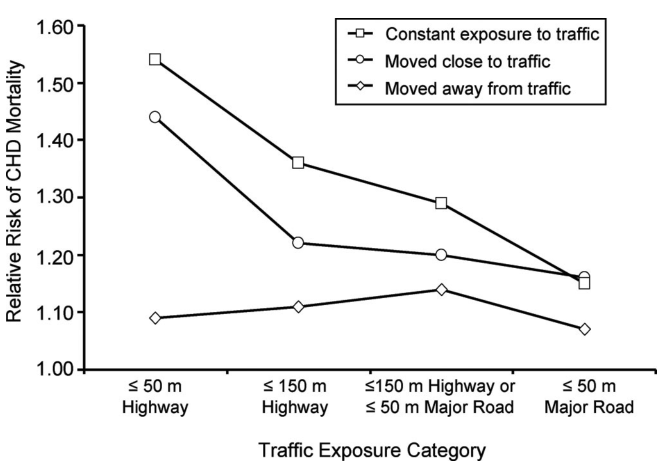


FIGURE 1. Association of road traffic exposure with coronary heart disease mortality by road types and distances. RRs adjusted for age, sex, neighborhood SES, and pre-existing comorbidities.

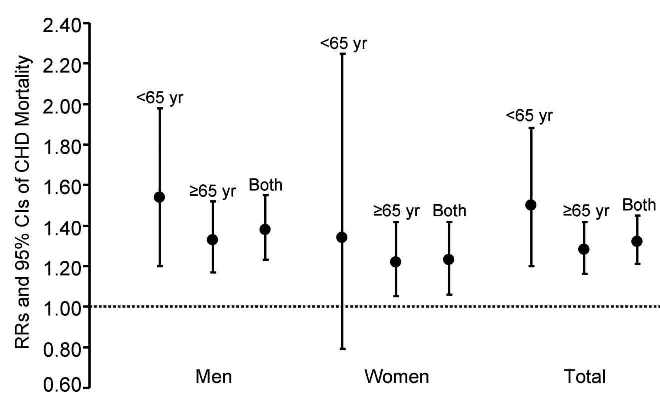


FIGURE 2. Association of road traffic exposure with coronary heart disease mortality by sex and age (traffic exposure was defined as ≤150 m highway or ≤50 m major road). Adjusted for neighborhood SES and pre-existing comorbidities; the combined analyses ("Both") were additionally adjusted for age (<65 years, ≥65 years); for the total group, the analyses were additionally adjusted for age (<65 years, ≥65 years) and sex.

In the sensitivity analysis examining the effects of distances and reference groups, for those who moved away from traffic during the exposure period, the effect estimates were very close among the 3 groups (Fig. 3). However, for those who moved close to or consistently lived close to traffic, the effect estimates changed in response to different distances and references used in the analysis, indicating that the observed association between residential proximity to traffic and the risk of CHD mortality was sensitive to distances from highways and the references used for comparison.

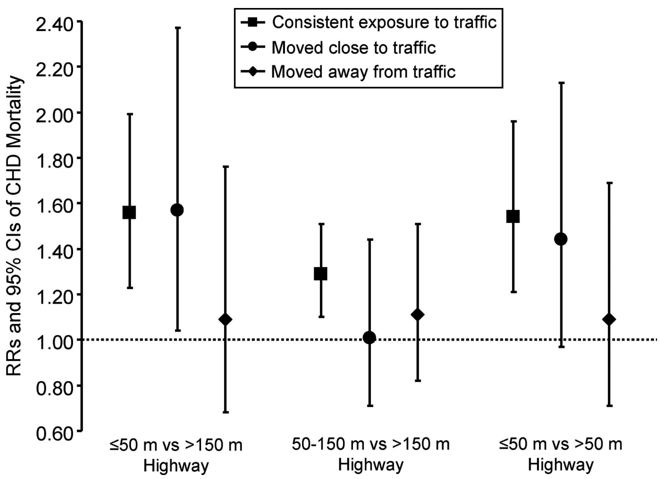


FIGURE 3. Association of road traffic exposure with coronary heart disease mortality by distances from highways. Adjusted for age, sex, neighborhood SES, and pre-existing comorbidities.

DISCUSSION

In this large population-based cohort study with detailed residential-history information, living close to road traffic was associated with an increased risk of CHD mortality. More importantly, a change in residential proximity to traffic was associated with an altered risk of CHD mortality: moving close to traffic was associated with a relatively increased risk, whereas moving away from traffic was associated with a relatively decreased risk.

Previous studies examining the associations between residential proximity to traffic and cardiovascular outcomes have not reported entirely consistent findings. A cross-sectional study carried out in Germany with 4494 participants found that living close to a major road was associated with more severe coronary artery calcification.[11] In contrast, a recent study with 1147 participants in the United States found no appreciable association between residential proximity to a major road and abdominal aortic calcification.[12] In a 13-year cohort study of 13,309 people in the United States, Kan et al[13] found that residential traffic intensity was associated with an increased risk of fatal and nonfatal coronary events. Similarly, in a large case-control study, Tonne et al[14] reported that living near a major road was associated with a 5% increase in the risk of acute myocardial infarction. A 13-year cohort study of 4800 women in Germany also found that living within 50 m of a major road was associated with increased cardiopulmonary mortality.[15] In contrast, in a 9-year Dutch cohort study with 117,528 participants, Beelen et al[16] did not find an association between residential proximity to a major road or residential traffic intensity and cardiovascular mortality. Several studies have also reported associations between exposures to traffic-related air pollutants such as nitrogen oxides and adverse cardiovascular outcomes.[17–19] Because of differences in traffic characteristics, study populations, meteorological and geographic conditions, study design, and statistical methods, it is difficult to quantitatively compare the results from different studies. Although the findings from these previous studies are not fully consistent, the present study and most previous studies suggest that residential proximity to traffic is associated with increased risk of CHD mortality. Traffic-related air pollution and other factors such as traffic noise may be responsible for the observed association.

Compared with previous reports, this study has several important strengths: First, this population-based cohort study may be regarded as a natural experiment in which we took advantage of detailed residential histories to investigate the relationship between changes in traffic exposure status and the risk of CHD mortality. Changes in residential proximity to traffic were associated with an altered risk of CHD mortality in an exposure-response fashion.

Second, we used various road types (highway or major road) and distances (≤50 or ≤150 m) from major roadways to assess residential proximity to traffic. The observed association was consistent across various combinations of road types and distances. The effect estimate was dependent on road types (traffic volume) and distances in a dose-response fashion (Table 3, Fig. 1).

Third, residential proximity to traffic was consistent with land-use-regression-model estimates for the concentrations of black carbon, nitrogen dioxide (NO_2), and nitric oxide (NO) (Table 2). These results are consistent with those of previous studies, and suggest that residential proximity to traffic is a simple and specific surrogate that reflects spatial variability of traffic-related air pollution.[5,6] In a separate analysis of associations between these 4 pollutants and the risk of CHD mortality, we found that an interquartile range elevation in the concentrations of black carbon was associated with a 6% (95% CI = 1.02–1.09) increase in the risk of CHD mortality after adjustment for all the covariates and 3 other copollutants ($PM_{2.5}$, NO_2, and NO); the corresponding relative risk for $PM_{2.5}$, NO_2, and NO was 1.00 (0.97–1.04), 1.04 (1.00–1.09), and 1.02 (0.97–1.08), respectively (Gan WQ, Koehoorn M, Daves HW, Demers PA, Tamburic L, Brauer M. Submitted paper).

Fourth, this study found that 47% of study subjects changed their residences at least once during the 9-year study period, leading to a change in the residential traffic exposure status in 15% of the subjects. When residential proximity to traffic at the original address (January 1994) was used to evaluate traffic exposure status (and subsequent residential relocations were ignored), the corresponding adjusted RRs (95% CI) for the 5 exposure categories were: 1.19 (1.10–1.29), 1.34 (1.10–1.64), 1.27 (1.13–1.42), 1.09 (0.99–1.21), and 1.06 (0.99–1.14) (Table 3, from the first to the fifth row). Thus, previous studies that have not accounted for residential relocation may have suffered from substantial exposure misclassification. This may result in underestimations of the true adverse health effects, and even false-negative results.

This study had several limitations that should be considered when interpreting these findings. The study cohort was constructed using linked administrative databases that did not include certain important information about individual cardiovascular risk factors (such as active or passive smoking status, body mass index, and individual SES). To partially control for these unmeasured risk factors, we adjusted for age, sex, neighborhood SES, and pre-existing comorbidities including diabetes, COPD, and hypertensive heart disease. Because these comorbidities and CHD share common behavioral risk factors, adjusting for these pre-existing comorbidities was presumably able to reduce the influence of uncontrolled factors, such as cigarette smoking, to some extent.[24] However, these approaches cannot eliminate all confounding effects caused by unmeasured cardiovascular risk factors.

Cigarette smoking is the single most important risk factor for CHD.[25] If smokers are more likely to live near (or move closer to) major roadways, the observed association may be confounded by the effects of cigarette smoking. However, previous epidemiologic studies have demonstrated that the association of air-pollution exposure with the severity of atherosclerosis[11,26] or the risk of CHD mortality[3,27] was independent of cigarette-smoking status and even stronger among never-smokers.[3,11,26,27] For example, Pope et al[3] reported that for each 10 μg/m^3 increase in annual average concentration of $PM_{2.5}$, the adjusted relative risk of CHD mortality was 1.22 for never smokers, 1.15 for former smokers, and 1.16 for current smokers. Given these findings and the lack of evidence to suggest that cigarette smoking is related to changes in residential proximity to traffic, it is less likely that the observed associations were due to confounding effects of cigarette smoking.

Low SES is a risk factor for CHD[28] and is also related to other cardiovascular risk factors such as cigarette smoking, obesity, and hypertension.[29–31] In some locations, people with low SES are more likely to live close to major roadways.[32] Individual SES is thus a possible confounder for the observed association. In the present study, we used neighborhood-income quintiles to approximate the major differences of economic status between subjects with various traffic-exposure profiles. Although this method may induce a degree of SES misclassification, some evidence has suggested that this approximation is acceptable for group comparisons.[33] In addition, some studies have found that neighborhood SES is associated with the risk of CHD independent of individual SES, indicating that adjustment for neighborhood SES may also reduce the influence of uncontrolled factors related to neighborhood disadvantages.[31] We used neighborhood income quintiles derived from the 2001 census data, which may not accurately reflect the original neighborhood SES for subjects who changed their residences during the exposure period (January 1994–December 1998). Nevertheless, there is evidence that the levels of neighborhood SES are well correlated for those who change their residences.[31]

Residential proximity to traffic is a relatively crude surrogate for exposure to traffic-related air pollution. Many factors, such as wind direction, presence of street canyons, and specific residence characteristics, may influence actual residential exposure levels.[34,35] Moreover, in the present study, residential proximity to traffic was estimated using the postal code centroid rather than the actual residential address. In urban areas, a 6-digit postal code typically represents one side of a city block or individual multiunit structures and is therefore fairly precise. Still, this assessment of traffic proximity will inevitably induce exposure misclassification. Furthermore, as in previous studies, our exposure assessment can only approximately reflect the exposure levels at subjects' residences, which may not precisely reflect actual individual exposure levels. Mobility,[36] outdoor activity, and indoor infiltration of air pollutants[37] may differ across study subjects. Nevertheless, all these factors presumably cause nondifferential exposure misclassification, leading to underestimations of the true adverse effects of residential proximity to traffic.

Finally, residential proximity to traffic signifies exposure not only to traffic-related air pollutants but also to traffic-related noise. Some studies have indicated that traffic-noise levels are at least moderately correlated with the concentrations of nitrogen oxides[38] and also with increased risk of CHD.[39] Therefore, it is possible that the increased risk of CHD mortality observed in the present study may be associated with both traffic-related air pollution and traffic noise. We cannot disentangle the effects of these 2 traffic-related pollutants in the current analysis.

An enormous number of people are regularly exposed to traffic; therefore, traffic-related air pollution may represent an important public-health problem. Using a large population-based cohort study with detailed residential history information, we observed that living close to traffic was associated with an increased risk of coronary mortality, whereas moving away from traffic was associated with a decreased risk.

REFERENCES

1. Brook RD, Rajagopalan S, Pope CA III, et al. Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association. *Circulation*. 2010;121:2331–2378.
2. Pope CA III, Dockery DW. Health effects of fine particulate air pollution: lines that connect. *J Air Waste Manag Assoc*. 2006;56:709–742.
3. Pope CA III, Burnett RT, Thurston GD, et al. Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. *Circulation*. 2004;109:71–77.
4. Miller KA, Siscovick DS, Sheppard L, et al. Long-term exposure to air pollution and incidence of cardiovascular events in women. *N Engl J Med*. 2007;356:447–458.

5. Brauer M, Hoek G, van Vliet P, et al. Estimating long-term average particulate air pollution concentrations: application of traffic indicators and geographic information systems. *Epidemiology*. 2003;14:228–239.
6. Zhu Y, Hinds WC, Kim S, Sioutas C. Concentration and size distribution of ultrafine particles near a major highway. *J Air Waste Manag Assoc*. 2002;52:1032–1042.
7. Kunzli N, Kaiser R, Medina S, et al. Public-health impact of outdoor and traffic-related air pollution: a European assessment. *Lancet*. 2000;356: 795–801.
8. Zhou Y, Levy JI. Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. *BMC Public Health*. 2007;7:
9. Adar SD, Kaufman JD. Cardiovascular disease and air pollutants: evaluating and improving epidemiological data implicating traffic exposure. *Inhal Toxicol*. 2007;19:135–149.
10. Jerrett M, Arain A, Kanaroglou P, et al. A review and evaluation of intra-urban air pollution exposure models. *J Expo Anal Environ Epidemiol*. 2005;15:185–204.
11. Hoffmann B, Moebus S, Mohlenkamp S, et al. Residential exposure to traffic is associated with coronary atherosclerosis. *Circulation*. 2007; 116:489–496.
12. Allen RW, Criqui MH, Diez Roux AV, et al. Fine particulate matter air pollution, proximity to traffic, and aortic atherosclerosis. *Epidemiology*. 2009;20:254–264.
13. Kan H, Heiss G, Rose KM, Whitsel EA, Lurmann F, London SJ. Prospective analysis of traffic exposure as a risk factor for incident coronary heart disease: the Atherosclerosis Risk in Communities (ARIC) study. *Environ Health Perspect*. 2008;116:1463–1468.
14. Tonne C, Melly S, Mittleman M, Coull B, Goldberg R, Schwartz J. A case-control analysis of exposure to traffic and acute myocardial infarction. *Environ Health Perspect*. 2007;115:53–57.
15. Gehring U, Heinrich J, Kramer U, et al. Long-term exposure to ambient air pollution and cardiopulmonary mortality in women. *Epidemiology*. 2006;17:545–551.
16. Beelen R, Hoek G, van den Brandt PA, et al. Long-term effects of traffic-related air pollution on mortality in a Dutch cohort (NLCS-AIR study). *Environ Health Perspect*. 2008;116:196–202.
17. Rosenlund M, Bellander T, Nordquist T, Alfredsson L. Traffic-generated air pollution and myocardial infarction. *Epidemiology*. 2009;20:265–271.
18. Rosenlund M, Picciotto S, Forastiere F, Stafoggia M, Perucci CA. Traffic-related air pollution in relation to incidence and prognosis of coronary heart disease. *Epidemiology*. 2008;19:121–128.
19. Nafstad P, Haheim LL, Wisloff T, et al. Urban air pollution and mortality in a cohort of Norwegian men. *Environ Health Perspect*. 2004;112:610–615.
20. Brauer M, Lencar C, Tamburic L, Koehoorn M, Demers P, Karr C. A cohort study of traffic-related air pollution impacts on birth outcomes. *Environ Health Perspect*. 2008;116:680–686.
21. Henderson SB, Beckerman B, Jerrett M, Brauer M. Application of land use regression to estimate long-term concentrations of traffic-related nitrogen oxides and fine particulate matter. *Environ Sci Technol*. 2007; 41:2422–2428.
22. Hole DJ, Watt GC, Davey-Smith G, Hart CL, Gillis CR, Hawthorne VM. Impaired lung function and mortality risk in men and women: findings from the Renfrew and Paisley prospective population study. *BMJ*. 1996;313:711–715.
23. Pearson TA, Blair SN, Daniels SR, et al; American Heart Association Science Advisory and Coordinating Committee. AHA guidelines for primary prevention of cardiovascular disease and stroke: 2002 update: consensus panel guide to comprehensive risk reduction for adult patients without coronary or other atherosclerotic vascular diseases. *Circulation*. 2002;106:388–391.
24. Pope CA III, Ezzati M, Dockery DW. Fine-particulate air pollution and life expectancy in the United States. *N Engl J Med*. 2009;360:376–386.
25. Ockene IS, Miller NH; For the American Heart Association Task Force on Risk Reduction. Cigarette smoking, cardiovascular disease, and stroke: a statement for healthcare professionals from the American Heart Association. *Circulation*. 1997;96:3243–3247.
26. Kunzli N, Jerrett M, Mack WJ, et al. Ambient air pollution and atherosclerosis in Los Angeles. *Environ Health Perspect*. 2005;113: 201–206.
27. Pope CA III, Burnett RT, Thun MJ, et al. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *JAMA*. 2002;287:1132–1141.
28. Kaplan GA, Keil JE. Socioeconomic factors and cardiovascular disease: a review of the literature. *Circulation*. 1993;88:1973–1998.
29. Luepker RV, Rosamond WD, Murphy R, et al. ; The Minnesota Heart Survey. Socioeconomic status and coronary heart disease risk factor trends. *Circulation*. 1993;88:2172–2179.
30. Auer JW, Berent R, Eber BC. Low socioeconomic status and coronary artery disease. *Lancet*. 2002;359:979–980.
31. Diez Roux AV, Merkin SS, Arnett D, et al. Neighborhood of residence and incidence of coronary heart disease. *N Engl J Med*. 2001;345:99–106.
32. Gunier RB, Hertz A, Von Behren J, Reynolds P. Traffic density in California: socioeconomic and ethnic differences among potentially exposed children. *J Expo Anal Environ Epidemiol*. 2003;13:240–246.
33. Domínguez-Berjón F, Borrell C, Rodríguez-Sanz M, Pastor V. The usefulness of area-based socioeconomic measures to monitor social inequalities in health in Southern Europe. *Eur J Public Health*. 2006; 16:54–61.
34. Xie SD, Zhang YH, Li Q, Tang XY. Spatial distribution of traffic-related pollutant concentrations in street canyons. *Atmos Environ*. 2003;37: 3213–3224.
35. Restrepo C, Zimmerman R, Thurston G, et al. A comparison of ground-level air quality data with New York State Department of Environmental Conservation monitoring stations data in South Bronx, New York. *Atmos Environ*. 2004;38:5295–5304.
36. Nethery E, Leckie SE, Teschke K, Brauer M. From measures to models: an evaluation of air pollution exposure assessment for epidemiological studies of pregnant women. *Occup Environ Med*. 2008;65:579–586.
37. Hystad PU, Setton EM, Allen RW, Keller PC, Brauer M. Modeling residential fine particulate matter infiltration for exposure assessment. *J Expo Sci Environ Epidemiol*. 2009;19:570–579.
38. Davies HW, Vlaanderen JJ, Henderson SB, Brauer M. Correlation between co-exposures to noise and air pollution from traffic sources. *Occup Environ Med*. 2009;66:347–350.
39. Babisch W, Beule B, Schust M, Kersten N, Ising H. Traffic noise and risk of myocardial infarction. *Epidemiology*. 2005;16:33–40.

Childhood Asthma and Exposure to Traffic and Nitrogen Dioxide

W. James Gauderman, Edward Avol,* Fred Lurmann,† Nino Kuenzli,* Frank Gilliland,* John Peters,* and Rob McConnell**

Background: Evidence for a causal relationship between traffic-related air pollution and asthma has not been consistent across studies, and comparisons among studies have been difficult because of the use of different indicators of exposure.

Methods: We examined the association between traffic-related pollution and childhood asthma in 208 children from 10 southern California communities using multiple indicators of exposure. Study subjects were randomly selected from participants in the Children's Health Study. Outdoor nitrogen dioxide (NO_2) was measured in summer and winter outside the home of each child. We also determined residential distance to the nearest freeway, traffic volumes on roadways within 150 meters, and model-based estimates of pollution from nearby roadways.

Results: Lifetime history of doctor-diagnosed asthma was associated with outdoor NO_2; the odds ratio (OR) was 1.83 (95% confidence interval = 1.04–3.22) per increase of 1 interquartile range (IQR = 5.7 ppb) in exposure. We also observed increased asthma associated with closer residential distance to a freeway (2.22 per IQR; 1.36–3.63) and with model-based estimates of outdoor pollution from a freeway (1.89 per IQR; 1.19–3.02). These 2 indicators of freeway exposure and measured NO_2 concentrations were also associated with wheezing and use of asthma medication. Asthma was not associated with traffic volumes on roadways within 150 meters of homes or with model-based estimates of pollution from nonfreeway roads.

Conclusions: These results indicate that respiratory health in children is adversely affected by local exposures to outdoor NO_2 or other freeway-related pollutants.

(*Epidemiology* 2005;16: 000–000)

Submitted 12 October 2004; accepted 7 February 2005.
From the *Department of Preventive Medicine, University of Southern California Keck School of Medicine, Los Angeles, California; and †Sonoma Technology, Inc., Petaluma, California.
Supported in part by the California Air Resources Board (Contract A033-186), the National Institute of Environmental Health Sciences (5P30ES07048 and 1P01ES11627), the Southern California Particle Center and Supersite, the Environmental Protection Agency (grant R 82670801), and the Hastings Foundation.
e Supplemental material for this article is available with the online version of the journal at www.epidem.com; click on "Article Plus."
Correspondence: W. James Gauderman, Department of Preventive Medicine, University of Southern California, 1540 Alcazar St., Suite 220, Los Angeles, CA 90089. E-mail: jimg@usc.edu.

ISSN: 1044-3983/05/1606-0001
DOI: 10.1097/01.ede.0000181308.51440.75

Previous studies have demonstrated a link between outdoor air pollution and the occurrence of symptoms in children already diagnosed with asthma.[1] However, results are not consistent with respect to whether air pollution causes asthma. Most studies have found little evidence to support an association between community-average exposures to air pollution and community asthma prevalence.[2] These study designs failed to account for the variability in exposure resulting from vehicular traffic in urban areas. Asthma has been associated with local variation in traffic patterns within communities in many,[3–7] but not all,[8–11] studies that have examined the impact of local traffic. One possible reason for the inconsistency in these recent studies is the use of different indicators of traffic-related pollution. Some have measured pollutant exposure at home, some have estimated traffic volume near the home, and some have estimated exposure to traffic-related pollutants at home based on dispersion models. Little work has been done to validate estimates of traffic exposure against measured pollution concentrations. Most studies have been conducted in European cities, which differ from U.S. cities in the layout of streets and homes, and also in the relative proportion of diesel- to gasoline-powered vehicles.

We evaluated several commonly available indicators of traffic exposure and compared them with nitrogen dioxide (NO_2) levels measured at the homes of subjects participating in the Children's Health Study. The Children's Health Study was initiated in 1993 with a cohort of school-aged children from 12 southern California communities representing a wide range in air quality. To date, this study has reported associations between air pollution and several outcomes, including lung function,[12–15] respiratory symptoms in asthmatics,[16,17] and asthma incidence.[18] These analyses have relied on comparisons of average health across communities in relation to the pollution levels measured at a central site monitor in each community. In 2000, we conducted a study to measure NO_2 levels at a random sample of children's homes within each of the study communities. We examine how local variation in NO_2 and indicators of exposure to traffic-related pollutants are related to each other, and whether they are associated with lifetime prevalence of asthma and asthma-related outcomes.

METHODS

Study Subjects

In calendar year 2000, we measured outdoor NO_2 levels at the homes of randomly selected participants in the Children's Health Study. Eligible children included those who were originally enrolled as fourth graders (average age = 10 years) in 1993 (cohort 1) or 1996 (cohort 2), with the additional criteria that in 2000, they were still actively participating in the study and had lived in the same home since study enrollment. We excluded 2 of the 12 study communities (Lompoc and Lake Arrowhead) from this study, because neither has any major sources of traffic. From the pool of 890 eligible subjects, we randomly sampled 229 children for NO_2 monitoring. Samplers were deployed outside each home for 2-week periods in the summer and fall of 2000. Valid measurements in both seasons were obtained at 208 (91%) of the homes. Reasons for invalid measurements included lost samplers, subjects who moved, and difficulties with field access or deployment. The study protocol was approved by the Institutional Review Board for Human Studies at the University of Southern California, and informed consent was provided by a parent or legal guardian for all study subjects.

Nitrogen Dioxide Sampling

Ambient NO_2 was sampled with Palmes tubes.[19] These diffusion-based samplers have been widely used in several microenvironmental and personal air quality studies.[20–22] We deployed samplers outside the homes of study subjects, thus avoiding previously identified confounders such as indoor nitrous acid formation, gas stoves, or wall heaters. Samplers were attached at the roofline eaves, signposts, or rain gutters at an approximate height of 2 meters above the ground, oriented in a downward position and protected by an oversized paper cup. Duplicate samplers and field travel blanks were randomly assigned to approximately 10% of the subjects' homes. Samplers were deployed for 2-week periods in both summer (mid-August) and fall (mid-November) in all communities. Deployment across communities was accomplished over a 4-day period at the start of the summer and fall field sampling periods. Within any 1 community, samplers at all locations were deployed within a 4-hour period, and 2 weeks later the samplers were retrieved within a 4-hour period. Samplers were transported to and from the field in cooled portable ice chests. The samplers were prepared for field use and analyzed at the Harvard School of Public Health.

Traffic Exposures

We characterized exposure of each study participant to traffic-related pollutants by 3 metrics: (1) proximity of the residence to the nearest freeway; (2) average number of vehicles traveling within 150 meters of the residence each day, including vehicles on freeways, arterials, major collector roads, and (where available) on minor collector roads; and (3) model-based estimates of traffic-related air pollution at the residence, derived from dispersion models that incorporate distance to roadways, vehicle counts, vehicle emission rates, and meteorologic conditions. Methods used to estimate each of these exposure factors are described subsequently.

Residence addresses were standardized and their locations geocoded using the TeleAtlas database and software (Tele Atlas Inc., Menlo Park, CA, www.na.teleatlas.com). We used the TeleAtlas MultiNet USA database, a comprehensive geo-positioning-satellite-accurate database of roadways, for all analyses because it is more accurate than the standard files available from the U.S. Census. To estimate distance to the nearest freeway, we used ERSI ArcGIS Version 8.3 (ESRI, Redland, CA, www.esri.com) software tools to calculate the distance from each residence to the nearest interstate freeway, U.S. highway, or limited access highway. In these calculations, each direction of travel was represented as a separate roadway, and the "distance to nearest freeway" was the shortest distance from the residence to the middle of the nearest set of lanes of the freeway.

To estimate vehicle counts near homes, annual average daily traffic volumes were obtained from the California Department of Transportation (CALTRANS) Highway Performance Monitoring System for the year 2000. The traffic volumes were transferred from the CALTRANS roadway network to the TeleAtlas networks using previously described methods.[23] The hourly traffic volumes on weekdays and weekend days were estimated from the annual average daily traffic volumes and the average diurnal and day-of-week freeway and nonfreeway traffic variations observed in Southern California. These data were used to calculate the daily average number of vehicles traveling within 150 meters of each residence, weighted by inverse distance from the home to each road. This local traffic density was expressed as traffic volume per square meter.

To obtain model-based estimates of traffic-related pollution exposure, we used the CALINE4 line-source air-quality dispersion model.[24] Principal model inputs included roadway link geometry, link traffic volumes, meteorologic conditions (wind speed and direction, atmospheric stability, and mixing heights), and vehicle emission rates. The 5-year average joint distributions of wind speeds and directions were obtained from 1 surface-monitoring station in or near each study community. The dispersion model was applied to simulate the transport and dispersion of NO_x as a chemically inert pollutant. Although NO, NO_2, and ozone undergo rapid atmospheric chemical reactions immediately downwind of sources, NO_x can be treated as a chemically inert pollutant for the first hour of transport from sources because the time-scale for NO_x oxidation is 10 to 20 hours in urban atmospheres.[25] Vehicle NO_x emission rates were obtained from the California Air Resources Board's EMFAC2002 vehicle emissions model. Concentrations of NO_2 were estimated by applying the annual average ratio of observed NO_2 to NO_x for each hour of the day (from the community central site monitor) to the CALINE4 model's estimated NO_x concentrations. We estimated the contribution to residential exposure separately for freeway and for nonfreeway traffic.

Ambient NO_2 concentrations in the community are a result of meteorologic transport of pollutants into the community, local point and area source emissions, and local mobile source emissions. The CALINE4 model was used to model NO_2 from local traffic in each community and, therefore, always predicts concentrations lower than the total NO_2 from all sources. Separate regional modeling analysis has indicated that local mobile source emissions contribute 12% to 68% of the average NO_2 in the study communities.[23] For comparison purposes, we also generated exposure assignments based on fine particulate matter (PM) and carbon monoxide (CO) emission factors. Model-based estimates of NO_2, PM, and CO were very highly correlated with one another ($R > 0.90$), indicating that the NO_2-based estimates we use in this article should be considered an estimate of traffic-related pollution in general rather than simply exposure to this specific pollutant.

Questionnaire Data

When we originally enrolled subjects as fourth graders, each subject's parent or legal guardian completed a baseline medical history questionnaire. Asthma was defined as a "yes" response to the question "Has a doctor ever diagnosed your child as having asthma?" This questionnaire was also used to determine whether the child had recently (within the last 12 months) wheezed, recently wheezed during exercise, or was currently using any type of medication to control asthma. Questions about potential risk factors for asthma included parental income or education, environmental tobacco smoke exposure, in utero exposure to maternal tobacco smoking, and presence in the home of mildew, water damage, gas stove, pests, and pets.

Statistical Analysis

We used logistic regression to model the relationship of each traffic measure, including measured NO_2 at the home and the traffic indicators described previously, with baseline asthma prevalence in the 208 study participants. A natural-log transformation of each traffic indicator was used in these analyses, because the distribution of each variable was positively skewed. All models included adjustments for sex, race, Hispanic ethnicity, cohort (whether the subject was enrolled in 1993 or 1996), and indicator variables for study community. We considered separate models for 2-week average NO_2 concentrations measured in summer and in winter and for the 4-week average across seasons. Odds ratios (ORs) for asthma in analyses of measured NO_2 concentrations were scaled to an increase of 5.7 ppb, the average interquartile range (IQR) in 4-week average NO_2 within the 10 communities. ORs for the traffic indicators were also scaled to 1 IQR in exposure (specifically 1.2 km for distance to the nearest freeway; 2720 vehicles per m^2 per day for traffic volumes within 150 meters; and 0.64, 0.49, and 1.27 ppb for model-based estimates of NO_2 from freeways, nonfreeways, and all roads, respectively).

RESULTS

Doctor-diagnosed asthma was reported by 31 (15%) of the 208 children, with variability in prevalence across communities (Table 1). Overall community-average NO_2 levels measured at homes ranged from 12.9 ppb in Atascadero to 51.5 ppb in San Dimas, with similar patterns across communities in summer and winter. The NO_2 levels (average of summer and winter) measured at homes are shown in Figure 1. Within each community, there was substantial variation in NO_2 levels from home to home. Although the amount of variation in NO_2 was generally larger in more polluted communities, there were some exceptions. For example, there was little variation in the relatively high NO_2 community of Mira Loma, whereas there was considerable variation in the lower NO_2 community of Alpine.

The average NO_2 concentration measured at homes was associated with asthma prevalence (Table 2). For each increase of 5.7 ppb in average NO_2, the OR for asthma increased by 1.83 (95% CI = 1.04–3.21). Odds ratios were similar whether based on summer-only (1.55) or winter-only (1.50) measurements. The effect of average NO_2 was of similar magnitude after adjustment for several potential confounders, including socioeconomic status of participants and housing characteristics (Table 2).

Measured NO_2 concentrations at homes were correlated with residential distance from the nearest freeway and with model-based estimates of traffic-related pollution from roadways (Appendix Table, available with the online version of this article). In each community, we observed negative correlations between NO_2 concentration and distance of the home to the freeway. The overall correlation between NO_2 and freeway distance, adjusted for community, was $R = -0.54$. The corresponding correlations of measured NO_2

TABLE 1. Distribution of Lifetime History of Asthma and Measured NO_2 by Community (n = 208)

Community	No.	Asthma (%)	NO_2 (ppb)		
			Summer	Winter	Average†
Alpine (AL)	24	21	20.1	19.0	19.6
Atascadero (AT)	13	23	12.3	13.6	12.9
Lake Elsinore (LE)	22	5	17.6	27.4	22.5
Lancaster (LN)	16	19	16.9	22.0	19.5
Long Beach (LB)	20	10	34.6	50.5	42.5
Mira Loma (ML)	17	12	37.2	48.4	42.8
Riverside (RV)	30	20	37.9	42.8	40.3
San Dimas (SD)	34	15	52.0	51.0	51.5
Santa Maria (SM)	19	16	12.7	17.9	15.3
Upland (UP)	13	8	46.3	36.0	41.2

*Parent report of doctor-diagnosed asthma in the child.
†Mean in each community of NO_2 concentrations measured at homes for 2 weeks each in summer and winter. Average is the 4-week arithmetic average of summer and winter measurements.

with model-based estimates were 0.56 for pollution from freeways and 0.34 for pollution from nonfreeways. In each community, measured NO_2 was more strongly correlated with estimates of freeway-related pollution than with nonfreeway pollution. Measured NO_2 was less correlated with traffic counts within 150 meters of homes (R = 0.24), with inconsistent patterns of correlations from community to community.

Both distance to the freeway and the model-based estimate of freeway-related pollutants were associated with asthma history (Table 3). Asthma prevalence was higher with decreasing distance from the freeway; specifically when comparing the 25th to 75th percentile of freeway distance, the OR was 1.89 (95% CI = 1.19–3.02). For the comparison of 75th to 25th percentile of model-based pollutant exposure from freeways, the OR was 2.22 (1.36–3.63). Asthma was not associated with traffic volumes or with model-based exposure to nonfreeway roads. The associations observed with freeway distance and model-based pollution from freeways were robust to adjustment for all of the potential confounders shown in Table 2 (data not shown).

Measured NO_2 and the 2 freeway-related traffic indicators were also associated with recent wheeze, recent wheeze with exercise, and current use of asthma medication

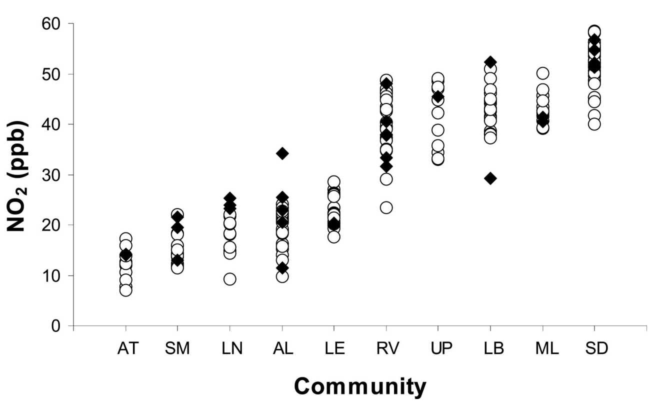


FIGURE 1. Four-week average of nitrogen dioxide measured at homes of asthmatic (solid black diamond) and nonasthmatic (open circle) children in 10 communities. See Table 1 for community abbreviations.

TABLE 2. Association Between 4-Week Average NO_2 at Homes and Asthma History, Adjusted for Several Potential Confounders

Description	OR* (95% CI)
Base model†	1.83 (1.04–3.21)
Base model, with additional adjustment for:	
Environmental tobacco smoke	1.93 (1.09–3.43)
In utero exposure to maternal smoking	1.85 (1.05–3.28)
Parental income	1.99 (1.11–3.57)
Parental education	1.90 (1.07–3.37)
Gas stove	1.87 (1.06–3.30)
Mildew	1.81 (1.01–3.23)
Water damage	1.82 (1.03–3.21)
Cockroaches	1.83 (1.04–3.21)
Pets	1.88 (1.06–3.33)

*Odds ratio per increase of 1 interquartile range (5.7 ppb) in NO_2.
†Base model includes adjustments for sex, race, Hispanic ethnicity, cohort, and community.

TABLE 3. Associations Between Exposure to Traffic at Home and Asthma History

Exposure Metric	Odds Ratio per IQR OR* (95% CI)
Distance to freeway	1.89 (1.19–3.02)
Traffic volume within 150 meters	1.45 (0.73–2.91)
Model-based pollution from:	
Freeways	2.22 (1.36–3.63)
Other roads	1.00 (0.75–1.33)
Freeways and other roads	1.40 (0.86–2.27)

*Odds ratio per change of 1 IQR. For distance to freeway, OR for the 25th percentile compared with the 75th percentile (ie, living closer compared with farther from the freeway). For remaining traffic variables, OR for the 75th percentile compared with the 25th percentile. All models were adjusted for sex, race, Hispanic ethnicity, cohort, and community.

(Table 4). For example, the OR per increase of 5.7 ppb in measured NO_2 was 1.72 (1.07–2.77) for recent wheeze and was 2.19 (1.20–4.01) for current use of asthma medication.

DISCUSSION

We found robust associations of several indicators of exposure to traffic-related air pollution at homes in southern California with lifetime history of asthma, current asthma medication use, recent wheeze, and recent exercise-induced wheeze. Residential distance to a freeway and model-based estimates of freeway traffic-emission exposure at homes were each associated with the prevalence of asthma. Each of these traffic metrics was also correlated with measured concentrations of NO_2, and measured NO_2 was associated with asthma. Taken as a whole, these results indicate that exposure to outdoor levels of NO_2 or other freeway-related pollutants was a significant risk factor for asthma.

A strength of this asthma study is that it used both measured pollution and multiple indicators of exposure to traffic at the same homes in a large number of communities. The results suggest that measuring NO_2 or another pollutant is important for validation of the use of traffic measures and for selection of the most appropriate indicator of traffic exposure for the population under study. Those few studies that have measured residential exposure or that have validated models of exposure using measurements of pollutants have generally shown associations with asthma,[6,7,26] whereas the failure to validate traffic indicators may explain inconsistent results from several other studies.[8–11] In our study, simple distance to a freeway was as strongly and precisely associated with asthma and wheeze as was NO_2. It remains to be seen whether the association with this simple and widely available indicator is replicable in other studies or could be used for estimating risk in communities without having to make additional measurements of traffic-related pollutants.

We did not find associations between respiratory health and other indicators of traffic near homes, including modeled pollution from nonfreeway roads and traffic volumes within 150 meters of homes. One possible explanation for this lack of association is that the contribution to pollution levels from these smaller roads (where tens or hundreds of vehicles travel each day) is trivial compared with freeways that dominate the transportation grid in southern California with daily average counts in our communities between 50,000 to 270,000 vehicles. In addition, vehicle counts are accurately measured on freeways but are only estimated on smaller roads where participants lived. Our results are in contrast to several recent (mostly European) studies that have reported associations of asthma with traffic counts in close proximity to the home.[6,7,27,28] These differences in results may be partly the result of differences in urban geography and closer proximity of homes in Europe to heavily traveled roadways.

There have been a few other studies of traffic and childhood asthma in the United States. One large study in southern California found no association of asthma prevalence with traffic counts within 550 feet of the home,[9] similar to our finding of no association with traffic volumes within 150 meters of the home. Consistent with our findings related to measured NO_2, a recent study in northern California[29] found an association between measured traffic-related pollutants at schools and childhood asthma.

TABLE 4. Associations Between Measured NO_2 and Asthma-Related Outcomes (n = 208)

Outcome	No.	Measured NO_2 OR* (95% CI)	Distance to Freeway OR* (95% CI)	Model-based Pollution From Freeways OR* (95% CI)
Lifetime history of asthma	31	1.83 (1.04–3.22)	1.89 (1.19–3.02)	2.22 (1.36–3.63)
Recent wheeze†	43	1.72 (1.07–2.77)	1.59 (1.06–2.36)	1.70 (1.12–2.58)
Recent wheeze with exercise†	25	2.01 (1.08–3.72)	2.57 (1.50–4.38)	2.56 (1.50–4.38)
Current asthma medication use	26	2.19 (1.20–4.01)	2.04 (1.25–3.31)	1.92 (1.18–3.12)

*Odds ratio per change of 1 IQR in exposure (see footnotes to Tables 2 and 4).
†Within the last 12 months.

The observed associations of traffic with asthma are biologically plausible. Increased oxidative and nitrosative stress associated with NO_2 exposure may impair respiratory responses to infection and thus result in lung injury and asthma exacerbation.[20,30] However, the association of NO_2 with asthma prevalence has been extensively evaluated in epidemiologic studies of exposure to indoor sources, often at levels considerably higher than the modest (5.7 ppb) IQR of exposure in our study, and the observed associations have not been consistent.[30,31] It is possible that outdoor NO_2, which occurs in a complex mixture that includes particulate matter and other pollutants known to affect respiratory health, is a marker of some other traffic-related pollutant(s) responsible for increasing asthma risk. For example, some field studies suggest that the concentration of fine particulate matter, especially black smoke (an indicator of diesel exhaust), varies with nearby high-traffic roads and with NO_2.[32–35] It has been hypothesized that particulate matter, especially diesel exhaust particulate, may contribute to the development of allergies and asthma.[36] Additional research is needed to study the health effects of specific pollutants that occur in complex mixtures of traffic emissions.

A possible limitation of this study is the assessment of asthma by questionnaire, which could be affected by access to care and differences in diagnostic practice among physicians.[37] However, we found associations of traffic indicators with recent wheeze and exercise-induced wheeze, 2 symptoms of asthma that are unlikely to be affected by access to care or diagnostic bias. Another limitation is the possibility of poor or biased reporting of asthma by parents. However, self-report of physician-diagnosed asthma has been found to reflect what physicians actually reported to patients, at least in adults, and validity as assessed by repeatability of response is good.[38] Self-report of physician diagnosis has been the main criterion for identifying asthma in epidemiologic studies of children and has been recommended as the epidemiologic gold standard because a more precise identification tool is not available.[39] Reporting bias is unlikely to have explained the observed associations, because parents were not aware of the specific focus of the study on air pollution at the time the questionnaire was completed. Biased participation with respect to disease status in this substudy is also unlikely, because the prevalence of doctor-diagnosed asthma in the sample of 208 children (15%, Table 1) was not very different from the asthma prevalence in the remaining 668 eligible children (13%, $P = 0.56$).

Another potential study limitation is that measured NO_2 and the traffic metrics were determined after the onset of asthma and extrapolated to earlier in life. However, the systems of freeways and other major roadways in the study communities have been in place and essentially unchanged for many years. We thus expect that the spatial pattern of exposure to traffic emissions from home to home was relatively similar over the lifetimes of these children. Bias could also have occurred if the families of asthmatic children had preferentially moved to a home near a freeway, but this seems unlikely. Additionally, our observed associations were robust to adjustment for factors known to be related to population mobility, housing location, and access to care, including race/ethnicity and indicators of socioeconomic status (as well as household characteristics). This robustness further suggests that our results were not the result of these potential confounders.

These results have both scientific and public health implications. They strengthen an emerging body of evidence that air pollution can cause asthma and that traffic-related pollutants that vary within communities are partly responsible for this association. The current regulatory approach that focuses almost exclusively on regional pollutants merits reevaluation in light of this emerging evidence and in light of the enormous costs associated with childhood asthma.[40] In addition, because NO_2 may be a surrogate for the pollutant or pollutants responsible for the observed effects, further study is indicated to identify the specific pollutant(s). In this regard, improved physical and chemical characterization of ambient ultrafine particles (including particle number concentration distributions, as well as more traditional chemical analyses) are topics of specific ongoing research interest in southern California and elsewhere.

ACKNOWLEDGMENTS

We are very grateful for input from the external advisory committee to this study, including David Bates, Morton Lippmann, Jonathan Samet, Frank Speizer, John Spengler, and Scott Zeger. We thank Tami Funk of Sonoma Technology for contributing to the assessment of residential distance to freeways, and Robert Weker of the Harvard School of Public Health for preparing and analyzing the Palmes tubes.

REFERENCES

1. Nicolai T. Air pollution and respiratory disease in children: what is the clinically relevant impact? *Pediatr Pulmonol Suppl*. 1999;18:9–13.
2. Clark NM, Brown RW, Parker E, et al. Childhood asthma. *Environ Health Perspect*. 1999;107(suppl 3):421–429.
3. Venn A, Lewis S, Cooper M, et al. Local road traffic activity and the prevalence, severity, and persistence of wheeze in school children: combined cross sectional and longitudinal study. *Occup Environ Med*. 2000;57:152–158.
4. Edwards J, Walters S, Griffiths RK. Hospital admissions for asthma in preschool children: relationship to major roads in Birmingham, United Kingdom. *Arch Environ Health*. 1994;49:223–227.
5. Hirsch T, Weiland SK, von Mutius E, et al. Inner city air pollution and respiratory health and atopy in children. *Eur Respir J*. 1999;14:669–677.
6. van Vliet P, Knape M, de Hartog J, et al. Motor vehicle exhaust and chronic respiratory symptoms in children living near freeways. *Environ Res*. 1997;74:122–132.
7. Nicolai T, Carr D, Weiland SK, et al. Urban traffic and pollutant exposure related to respiratory outcomes and atopy in a large sample of children. *Eur Respir J*. 2003;21:956–963.
8. Wjst M, Reitmeir P, Dold S, et al. Road traffic and adverse effects on respiratory health in children. *BMJ*. 1993;307:596–600.
9. English P, Neutra R, Scalf R, et al. Examining associations between childhood asthma and traffic flow using a geographic information

system. *Environ Health Perspect*. 1999;107:761–767.
10. Waldron G, Pottle B, Dod J. Asthma and the motorways—one district's experience. *J Public Health Med*. 1995;17:85–89.
11. Kramer U, Koch T, Ranft U, et al. Traffic-related air pollution is associated with atopy in children living in urban areas. *Epidemiology*. 2000;11:64–70.
12. Peters JM, Avol E, Gauderman WJ, et al. A study of twelve Southern California communities with differing levels and types of air pollution. II. Effects on pulmonary function. *Am J Respir Crit Care Med*. 1999; 159:768–775.
13. Gauderman WJ, McConnell R, Gilliland F, et al. Association between air pollution and lung function growth in southern California children. *Am J Respir Crit Care Med*. 2000;162:1383–1390.
14. Avol E, Gauderman W, Tan S, et al. Respiratory effects of relocating to areas of differing air pollution levels. *Am J Respir Crit Care Med*. 2001;164:2067–2072.
15. Gauderman WJ, Avol E, Gilliland F, et al. The effect of air pollution on lung function development in children aged 10 to 18 years. *New Engl J Med*. 2004;351:1057–1067.
16. McConnell R, Berhane K, Gilliland F, et al. Air pollution and bronchitic symptoms in southern California children with asthma. *Environ Health Perspect*. 1999;107:757–760.
17. McConnell R, Berhane K, Gilliland F, et al. Prospective study of air pollution and bronchitic symptoms in children with asthma. *Am J Respir Crit Care Med*. 2003;168:790–797.
18. McConnell R, Berhane K, Gilliland F, et al. Asthma in exercising children exposed to ozone: a cohort study. *Lancet*. 2002;359:386–391.
19. Palmes ED, Gunnison AF, DiMattio J, et al. Personal sampler for NO_2. *Journal of the American Industrial Hygiene Association*. 1976;37:570–577.
20. Linaker CH, Coggon D, Holgate ST, et al. Personal exposure to nitrogen dioxide and risk of airflow obstruction in asthmatic children with upper respiratory infection. *Thorax*. 2000;55:930–933.
21. Alm S, Mukala K, Pasanen P, et al. Personal NO2 exposures of preschool children in Helsinki. *J Expo Anal Environ Epidemiol*. 1998; 8:79–100.
22. Samet J, Lambert W, Skipper B, et al. Nitrogen dioxide and respiratory illnesses in infants. *Am Rev Respir Dis*. 1993;148:1258–1265.
23. Wu J, Lurmann F, Winer A, et al. Development of an individual exposure model for application to the Southern California children's health study. *Atmos Environ*. 2005;39:259–273.
24. Bensen P. *CALINE4—A Dispersion Model for Predicting Air Pollution Concentrations Near Roadways*. Sacramento: California Department of Transportation; 1989.
25. Trainer M, Parrish D, Goldan P, et al. Review of observation-based analysis of the regional factors influencing ozone concentrations. *Atmos Environ*. 2000;34:2045–2061.
26. Brauer M, Hoek G, Van Vliet P, et al. Air pollution from traffic and the development of respiratory infections and asthmatic and allergic symptoms in children. *Am J Respir Crit Care Med*. 2002;166:1092–1098.
27. Venn AJ, Lewis SA, Cooper M, et al. Living near a main road and the risk of wheezing illness in children. *Am J Respir Crit Care Med*. 2001;164:2177–2180.
28. Zmirou D, Gauvin S, Pin I, et al. Traffic related air pollution and incidence of childhood asthma: results of the Vesta case–control study. *J Epidemiol Community Health*. 2004;58:18–23.
29. Kim JJ, Smorodinsky S, Lipsett M, et al. Traffic-related air pollution near busy roads: the East Bay Children's Respiratory Health Study. *Am J Respir Crit Care Med*. 2004;170:520–526.
30. Health effects of outdoor air pollution. Part 2. Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society. *Am J Respir Crit Care Med*. 1996;153:477–498.
31. Bates DV. Observations on asthma. *Environ Health Perspect*. 1995; 103(suppl 6):243–247.
32. Brauer M, Hoek G, van Vliet P, et al. Estimating long-term average particulate air pollution concentrations: application of traffic indicators and geographic information systems. *Epidemiology*. 2003;14:228–239.
33. Fischer PH, Hoek G, Van Reeuwijka H, et al. Traffic-related differences in outdoor and indoor concentrations of particles and volatile organic compounds in Amsterdam. *Atmos Environ*. 2000;34:3713–3722.
34. Roorda-Knape MC, Janssen NAH, de Hartog JJ, et al. Air pollution from traffic in city districts near major motorways. *Atmos Environ*. 1998;32: 1921–1930.
35. Seaton A, Dennekamp M. Hypothesis: ill health associated with low concentrations of nitrogen dioxide—an effect of ultrafine particles? *Thorax*. 2003;58:1012–1015.
36. Li N, Kim S, Wang M, et al. Use of a stratified oxidative stress model to study the biological effects of ambient concentrated and diesel exhaust particulate matter. *Inhal Toxicol*. 2002;14:459–486.
37. Samet JM. Epidemiologic approaches for the identification of asthma. *Chest*. 1987;91:74S–78S.
38. Ehrlich RI, Du Toit D, Jordaan E, et al. Prevalence and reliability of asthma symptoms in primary school children in Cape Town. *Int J Epidemiol*. 1995;24:1138–1145.
39. Burr ML. Diagnosing asthma by questionnaire in epidemiological surveys [Editorial]. *Clin Exp Allergy*. 1992;22:509–510.
40. Smith DH, Malone DC, Lawson KA, et al. A national estimate of the economic costs of asthma. *Am J Respir Crit Care Med*. 1997;156:787–793.

Urban Air Pollution and Lung Cancer in Stockholm

Fredrik Nyberg,[1] Per Gustavsson,[3,4] Lars Järup,[2,5] Tom Bellander,[2] Niklas Berglind,[2] Robert Jakobsson,[3,4] and Göran Pershagen[1,2]

We conducted a population-based case-control study among men 40–75 years of age encompassing all cases of lung cancer 1985–1990 among stable residents of Stockholm County 1950–1990. Questionnaires to subjects or next-of-kin (primarily wives or children) elicited information regarding smoking and other risk factors, including occupational and residential histories. A high response rate (>85%) resulted in 1,042 cases and 2,364 controls. We created retrospective emission databases for NO_x/NO_2 and SO_2 as indicators of air pollution from road traffic and heating, respectively. We estimated local annual source-specific air pollution levels using validated dispersion models and we linked these levels to residential addresses using Geographical Information System (GIS) techniques. Average traffic-related NO_2 exposure over 30 years was associated with a relative risk (RR) of 1.2 (95% confidence interval 0.8–1.6) for the top decile of exposure, adjusted for tobacco smoking, socioeconomic status, residential radon, and occupational exposures. The data suggested a considerable latency period; the RR for the top decile of average traffic-related NO_2 exposure 20 years previously was 1.4 (1.0–2.0). Little association was observed for SO_2. Occupational exposure to asbestos, diesel exhaust, and other combustion products also increased the risk of lung cancer. Our results indicate that urban air pollution increases lung cancer risk and that vehicle emissions may be particularly important. (Epidemiology 2000;11:487–495)

Keywords: lung cancer, air pollution, case-control study, road traffic, NO_2, SO_2, smoking.

Epidemiologic studies from many countries have shown elevated risks of lung cancer in urban or industrially polluted areas, generally by up to 1.5 times, even when adjustment for smoking has been attempted.[1,2] Traffic-related air pollution is a growing concern today, but most of the available evidence relates to areas where motor vehicles were not the major source of air pollution. Nevertheless, studies on diesel-exposed occupational groups provide support for a causative role of traffic-related air pollution for lung cancer.[2] Recent population-based cohort studies with measured air pollution data have also indicated that lung cancer incidence is increased by 30–50% in areas with high ambient air pollution levels compared with areas with lower levels.[3–5]

A major deficiency of many previous studies is the lack of individual long-term data on air pollution exposure.[1] It is also unclear which sources of urban air pollution may be of importance. In many instances, the lack of individual-level air pollution data is likely to have obscured much of the true range of individual exposure. The resulting limited exposure contrast has also hampered analyses of interactions with smoking and other known risk factors for lung cancer, even when such information was available.

The present study was conceived with the specific aim of exploring the possible association of lung cancer and urban air pollution by using geographical information system (GIS) techniques to assign individual exposures to ambient air pollution from oxides of nitrogen (NO_x), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) from defined emission sources. These pollutants were chosen as suitable indicators of air pollution from road traffic and heating, which constituted the main local sources of air pollution. Individual data on smoking, occupational exposures, and some other risk factors were also collected and used for evaluation of confounding and possible interactions.

Methods

Study Subjects

The study population comprised men 40 to 75 years of age who were residents of Stockholm County at any time between January 1, 1985 and December 31, 1990.

From the [1]Division of Environmental Epidemiology, Institute of Environmental Medicine, Karolinska Institute, Stockholm; [2]Department of Environmental Health, Stockholm County Council, Stockholm; [3]Division of Occupational Health, Department of Public Health Sciences, Karolinska Institute, Stockholm; [4]Department of Occupational Health, Stockholm County Council, Stockholm. Lars Järup is presently affiliated with the [5]Department of Epidemiology and Public Health, Imperial College, London, UK.

Address reprint requests to: Fredrik Nyberg, Division of Environmental Epidemiology, Institute of Environmental Medicine, Karolinska Institute, Box 210, SE-171 77 Stockholm, Sweden.

The study was supported by the Swedish Environmental Protection Agency, the Swedish Council for Working Life, and Stockholm County Council.

Submitted September 8, 1999; final version accepted January 7, 2000.

Editors' note: See related editorial on page 485 of this issue.

TABLE 1. Response Rates and Vital Status of Lung Cancer Cases and Controls 1985–1990 in Stockholm, Sweden

	Cases		Population Controls		Mortality-Matched Controls	
Categories	No	%	No	%	No	%
Selected	1196	100	1441	100	1324	100
Non-response	154	13	167	12	234	18
Total included (response rate)	1042	87	1274	88	1090	82
Vital status of included individuals						
Alive at time of data collection	68	7	1001	79	117	11
Dead at time of data collection	974	93	273	21	973	89

An additional restriction was residence outside the county for at most 5 years between 1950 to 1990, a criterion approximately 70% fulfilled. In this study base, we identified 1,196 male lung cancer cases (ICD-7 code 162.1, diagnosed between January 1, 1985 and December 31, 1990) from the Stockholm County regional cancer registry, of whom 1,042 participated in the study (Table 1). Cases who were deceased and who were still alive were included. The diagnosis was based on histology for 78.3% and cytology for 20.4%.

Incidence density sampled controls were drawn in 1992 by random sampling from retrospective population registers covering Stockholm County, stratified on age (5-year categories) and calendar year of selection (1985 to 1990) of the cases. One control group (N = 1,274) was drawn from all individuals in the study population alive at the end of each selection year ("population" controls). As foreseen, more individuals in this group than among the cases were still alive at the time of data collection (Table 1). To allow an evaluation of possible bias from using proxy interviews for deceased individuals, primarily in our occupational analyses,[6] we recruited a second control group (N = 1,090), also frequency matched to the cases on vital status on December 31, 1990, using the Cause-of-Death Registry (mortality-matched controls). We excluded individuals who had died from smoking-related diagnoses[7] from this control group.[6]

Exposure Assessment

Data collection via postal questionnaire was performed from 1994 through 1996. The questionnaire was sent to living subjects, or to next-of-kin (primarily wives or children) for deceased study subjects. Several mail reminders, and follow-up telephone reminders and interviews ensured a high response rate (over 85%, Table 1). The questionnaire inquired about smoking and dietary intake of vegetables and fruits, as well as detailed occupational and residential histories. For the assessment of air pollution exposure, the addresses of all residences after 1950 inhabited for over 1 year were collected. When the questionnaire residence history from 1950 was not complete, parish offices and tax authorities provided additional data. For the classification of residential radon exposure, questions concerning building materials, house type, and ground contact of dwelling were also asked.[8] All collected data were truncated at the individual selection year.

The geocoding and air pollution exposure assessment methodology using GIS is described in detail elsewhere.[9] Briefly, the addresses were transformed into geographical coordinates using standard GIS computer software[10] in conjunction with a regional geographical address data base.[11] The reference point for assessment of air pollution exposure was a detailed regional emission database for 1993[12] (see also http://www.slb.mf.stockholm.se/) containing approximately 4,300 traffic-related line sources covering all roads with over 1,000 vehicles/24 hr (90% of the estimated emission from road traffic), as well as over 500 point sources (district heating facilities, industries, etc.). Limited diffuse emission sources (*eg*, air traffic and merchant vessels) are mapped as area sources, and population-density related sources (*eg*, local heating, work machines) as grid-sources (250 or 1,000 m grids).

In this study, the estimated contributions to the total ambient NO_x/NO_2 and SO_2 levels from the relevant sources were used as markers for air pollution from road traffic and residential heating, respectively, based on source-specific emission data. These sources form the major part of ambient NO_x/NO_2 and SO_2 levels, respectively, in Stockholm County. We assessed area-wide emissions of traffic-related air pollution (NO_x and NO_2 from road traffic) for three periods: the 1960s, 1970s, and 1980s. Data on the expansion of built-up areas in Stockholm County and the growth and distribution of road traffic was collected from 1960 through 1993 to reconstruct comparable historical emission databases based on the 1993 database. Similarly, for emissions of SO_2 from heating sources, three corresponding historical emission databases were reconstructed using data on the sulfur content in oil and the development of district heating (point sources) and other energy plants. Available SO_2 measurement data were also used to calibrate the model regarding average emission levels from grid-type sources (mainly local oil-fuelled residential heating).

Dispersion calculations for annual mean SO_2 and NO_x from these emission databases used a Gaussian model,[13,14] in resolutions up to 100×100 m. The NO_x concentrations were transformed to NO_2 data using a non-linear relation derived from measurements in Stockholm County in the early 1980s. The dispersion model calculations from the NO_x/NO_2 1980s database (extended for this purpose to include traffic-related as well as other sources to produce estimates of total NO_x/NO_2) was compared with actual measurements of NO_2 at six roof-top or background sites. The modeled values in these points were within ±20% from observed annual means. As all available measurements for SO_2 were used for model calibration, a similar validation was not possible for SO_2, although the calibration as such implies that the model approaches the measured data.

Annual levels of SO_2 and NO_x/NO_2 were computed for each year between 1950 and 1990 by linear extrapolation and interpolation from the three database values, based on historical traffic counts for NO_2, and available trend data for SO_2 concentrations in Stockholm.[9] For main streets in the city center, street contributions of NO_x and NO_2 concentrations were added to the roof concentrations. These contributions were assessed by dispersion calculations with a street canyon model[14] and summarized in a 50% addition at street level and 20% at mid-facade.

Finally, the air pollution data for relevant time periods were linked to the nearly 11,000 individual address coordinates of the study subjects, yielding exposure indices for each of the three air pollution indicators for each year.

Data Analysis

The occupational history included information on company names and locations, occupations, and work tasks for work periods of at least 1 year. We classified occupations according to the Nordic occupational code (NYK-83).[15] Classification of overall exposure to known or suspected occupational lung carcinogens used a published job-exposure matrix and was based on an individual's entire occupational history.[16,17] An occupational hygienist evaluated exposure to specific occupational carcinogens including diesel exhaust, other combustion products, and asbestos for each work period, case-by-case, assigning an intensity class and a probability of exposure for each work period and substance. We calculated the cumulative exposure for each factor as the product of the intensity, the probability, and the duration of exposure, summed over all work periods in the occupational history.[6] Subjects were also categorized as to predominantly blue or white collar work and approximate educational level implied by their occupational history, by matching NYK-83 job titles to Swedish socioeconomic level (SEI) codes.[18,19] The resulting socioeconomic variable represents a cross-classification of blue/white collar and low/high educational level. We estimated radon exposure for each residence from an equation predicting radon levels based on geographical radon risk level, building material and house type, obtained by regressing 9,002 measured houses from a nationwide Swedish radon study[8] on these variables. Time-weighted average radon exposure was calculated over all available residences 30 to 3 years before end of follow-up.

We controlled confounding from smoking by a categorical variable (never; former smokers since >2 years; current smokers of 1–10, 11–20, and >20 cigarettes daily on average) and continuous variables for years since quitting among former smokers and average amount smoked among current smokers, respectively (set to 0 for other subjects). Missing values for seven former smokers and two smokers of 1–10 cigarettes were replaced by the average corresponding value among controls.

Geocoded air pollution information was available from 1950 to each subject's selection year, with at most 5 years of missing values for any individual, mainly due to residency outside Stockholm county and to less complete address data in early years. Since we considered extrapolation far back from the 1960s air-pollution database to be uncertain, we used only a 30-year period before the selection year to estimate air-pollution exposure for each individual (*ie*, 1955–1984 to 1960–1989 for selection year 1985 to 1990, respectively). We excluded the selection year since annual exposure values were used and individual exposure in the selection year varies depending on a subject's exact selection date. In the 30-year study period for air pollution exposure thus defined, geocoded data were missing for only 159 residential exposure years (0.16%) among all 3,406 individuals; 75 individuals with at most 4 of 30 years missing. We calculated time-weighted average exposures over the study period and specific time windows.[20,21] Exposure-response relations were very similar for NO_x and NO_2 and only results for NO_2 are presented, since routine monitoring of this pollutant is more widespread. Furthermore, the correlation between the 30-year estimated traffic-related averages of the two pollutants was 0.98.

We estimated relative risks (RR) and 95% confidence intervals (CI) by odds ratios from multiple unconditional logistic regression, using the program Stata®.[22] The full models were adjusted for matching variables (age and selection year) and potential confounders: smoking, radon, socioeconomic grouping, work in risk occupations and occupational exposure to diesel exhaust, other combustion products and asbestos. Categorical variables were coded with indicator (dummy) variables. Results using either control group were similar and we combined the two groups to provide optimal statistical stability. We calculated attributable risks based on category-specific relative risks according to standard formulae.[21]

Results

Relative risks for lung cancer associated with some risk factors are shown in Table 2. Smoking-related RRs ranged up to 34.6 (95% CI = 23.2–51.6) for current smokers with more than 20 cigarettes per day of average consumption. With adjustment for age in narrow 5-year intervals, used in the case-control matching, exposure intensity rather than duration was more strongly related to lung cancer risk among current smokers, and among former smokers the RR decreased with longer duration since quitting smoking (detailed data not shown). The RR associated with residential radon exposure was 1.13 (95% CI = 0.83–1.55) per 100 Bq/m,[3] assigning category means (see Table 2) as individual exposure level. Relative risks for three specific occupational exposures

TABLE 2. Relative Risk of Lung Cancer (and 95% Confidence Interval) Associated with Smoking, Radon, Socioeconomic Status, Some Occupational Exposures and Employment in Risk Occupations

Variable	Cases	Controls	RR*	95% CI*
Smoking†,‡,§,‖				
Never smokers**	36	705	1	
Former smokers	273	844	6.19	4.30–8.90
Current smokers				
1–10 cig/day	143	313	8.45	5.70–12.5
11–20 cig/day	348	363	18.4	12.7–26.6
>20 cig/day	242	139	34.6	23.2–51.6
Estimated residential radon exposure‡,§,‖,¶				
Below 78 Bq/m^3 (cat. mean 68)**	272	579	1	
78–93 Bq/m^3 (cat. mean 85)	265	587	0.94	0.74–1.19
93–116 Bq/m^3 (cat. mean 106)	280	572	1.08	0.85–1.37
Above 116 Bq/m^3 (cat. mean 147)	225	626	1.07	0.83–1.39
Broad socioeconomic groupings†,§,‖,¶				
Unskilled blue collar**	291	488	1	
Skilled blue collar, farmer	352	677	0.92	0.73–1.15
Unskilled white collar	136	333	0.87	0.65–1.16
Skilled white collar	263	866	0.74	0.58–0.95
Occupational exposure to diesel exhaust†,‡,‖,¶,††				
None or low**	970	2262	1	
High (≥2.38 mg-years/m^3 NO_2)	72	102	1.41	0.97–2.05
Occupational exposure to other combustion products†,‡,‖,¶,††				
None or low**	969	2268	1	
High (≥23.9 μg-years/m^3 benzo(a) pyrene)	73	96	1.47	1.01–2.14
Occupational exposure to asbestos†,‡,‖,¶,††				
None or low**	909	2189	1	
High (≥0.89 fiber-years/mL)	133	175	1.47	1.10–1.97
Employed in risk occupations†,‡,§,¶				
Never**	721	1802	1	
Ever	321	562	1.15	0.95–1.41

* All RRs adjusted for age, selection year, and exposure to traffic related air pollution.
† Additionally adjusted for radon.
‡ Additionally adjusted for socioeconomic grouping.
§ Additionally adjusted for occupational exposure to diesel exhaust, other combustion products, and asbestos.
‖ Additionally adjusted for employment in risk occupations.
¶ Additionally adjusted for smoking.
** Referent category.
†† Dichotomization of a cumulative exposure variable.

(diesel exhaust, other combustion products, and asbestos) were in the range 1.4–1.5. After adjustment for these exposures, the remaining relative risk for employment in risk occupations was 1.15 (Table 2). Low socioeconomic status was independently associated with increased risk. Variables for vegetable and fruit consumption were strongly protective in models that were adjusted only for the matching variables age and selection year (down to RR 0.3 for highest *versus* lowest consumption). These effects, however, largely disappeared when other risk factors (particularly smoking and socioeconomic status) were entered into the model. The dietary variables did not further confound the relation between air pollution and lung cancer. In addition, some subjects had missing dietary data, and thus we did not include the dietary variables in the final air pollution models.

The initial air pollution analyses utilized data covering the entire defined 30-year exposure period (Table 3). After we adjusted for the potential confounders identified, we found a weak effect for the 30-year average traffic-related NO_2 exposure, whereas we found no increase in risk of lung cancer associated with long-term average SO_2 exposure. In models incorporating both pollutants, the estimated effect of NO_2 was stronger.

We further investigated time windows and lags for calculating the individual mean exposure. Continuous and dichotomized NO_2 variables (representing linear component of trend and risk from extreme exposure, respectively) showed stronger positive associations with lung cancer risk than SO_2 variables, rather consistently regardless of time window used and particularly when early exposure (*ie*, 3rd decade before selection) was included. With a 20-year lag (*ie*, using a 10-year average over 21–30 years ago), the effects for traffic-related NO_2 exposure thus appeared stronger than for average exposure over the whole 30-year period, and showed a clearer dose-response (Table 4). When we examined exposures in the three different decades of the exposure period separately and jointly in regression models,[21] the results indicated that the earliest decade, 20 years before the selection year, was particularly important for lung cancer risk from traffic-related air pollution. The relative risk from traffic-related NO_2 exposure 21–30 years ago appeared relatively independent of smoking habits, *ie*, suggestive of an almost multiplicative interaction between the risks from these exposures. Heavy smokers constituted an exception, where no risk from traffic-related air pollution was indicated, although the confidence inter-

TABLE 3. Relative Risk of Lung Cancer (and 95% Confidence Interval) Associated with Long-Term (30-Year) Averages of Two Exposure Indicators for Air Pollution (NO_2 for Traffic-Related Air Pollution and SO_2 for Air Pollution from Heating)

			One Pollutant*		Both Pollutants†	
Variable	Cases	Controls	RR‡	95% CI‡	RR‡	95% CI‡
NO_2 from road traffic						
Continuous variable (per 10 $\mu g/m^3$)			1.05	0.93–1.18	1.08	0.93–1.27
Quartiles and 90th percentile						
<15.20 $\mu g/m^3$§	242	609	1		1	
≥15.20 to <19.85 $\mu g/m^3$	276	575	1.18	0.93–1.49	1.22	0.93–1.61
≥19.85 to <25.06 $\mu g/m^3$	252	600	0.90	0.71–1.14	0.96	0.72–1.30
≥25.06 to <30.55 $\mu g/m^3$	160	351	1.05	0.79–1.40	1.13	0.81–1.58
≥30.55 $\mu g/m^3$	112	229	1.17	0.84–1.62	1.28	0.87–1.88
SO_2 from heating						
Continuous variable (per 10 $\mu g/m^3$)			1.00	0.96–1.05	0.98	0.92–1.04
Quartiles and 90th percentile						
<41.30 $\mu g/m^3$§	245	606	1		1	
≥41.30 to <52.75 $\mu g/m^3$	254	598	1.06	0.83–1.35	1.00	0.77–1.31
≥52.75 to <67.14 $\mu g/m^3$	272	579	0.98	0.77–1.24	0.92	0.69–1.22
≥67.14 to <78.20 $\mu g/m^3$	152	359	0.90	0.68–1.19	0.85	0.61–1.20
≥78.20 $\mu g/m^3$	119	222	1.00	0.73–1.37	0.92	0.63–1.34

Estimated time weighted average air pollution exposure 1–30 years before end of follow-up.
* Estimate obtained when only one pollutant was entered into the regression model.
† Estimate obtained when the corresponding variable for the other pollutant (SO_2 or NO_2) was entered separately into the same regression model as a confounder. For example, point estimates 1.08 (NO_2) and 0.98 (SO_2) for the continuous air pollution variables are obtained from the same model, and similarly for the categorical variable results.
‡ Adjusted for age, selection year, smoking, radon, socioeconomic grouping, occupational exposure to diesel exhaust, other combustion products, and asbestos and employment in risk occupations.
§ Referent category.

val is compatible with a similar RR in this group (Table 5).

Despite high exposure levels in the early years of the study period, heating-related SO_2 showed little effect in any time window. The results were different from those obtained for NO_2, despite the fact that the 30-year averages of estimated individual SO_2 and NO_2 exposure showed some correlation (Pearson's correlation 0.64). Correlations were highest in the early years; for annual averages, they were around 0.7 for the years 1950–1968 and 0.5 for the years 1969–1990 and similar for cases and controls.

When the two different control groups were evaluated separately, results were similar. The point estimates for the 90th percentile of 10-year average traffic-related NO_2 exposure 20 years before selection were 1.45 for "population" controls and 1.49 for mortality-matched controls as compared with 1.44 (95% CI = 1.05–1.99) when

TABLE 4. Relative Risk of Lung Cancer (and 95% Confidence Interval) Associated with 10-Year Averages of Two Exposure Indicators for Air Pollution (NO_2 for Traffic-Related Air Pollution and SO_2 for Air Pollution from Heating) Lagged 20 Years

			One Pollutant*		Both Pollutants†	
Variable	Cases	Controls	RR‡	95% CI‡	RR‡	95% CI‡
NO_2 from road traffic						
Continuous variable (per 10 $\mu g/m^3$)			1.10	0.97–1.23	1.15	0.97–1.35
Quartiles and 90th percentile						
<12.78 $\mu g/m^3$§	243	608	1		1	
≥12.78 to <17.35 $\mu g/m^3$	264	588	1.15	0.91–1.46	1.19	0.91–1.56
≥17.35 to <23.17 $\mu g/m^3$	250	601	1.01	0.79–1.29	1.11	0.83–1.48
≥23.17 to <29.26 $\mu g/m^3$	165	346	1.07	0.81–1.42	1.19	0.86–1.66
≥29.26 $\mu g/m^3$	120	221	1.44	1.05–1.99	1.60	1.07–2.39
SO_2 from heating						
Continuous variable (per 10 $\mu g/m^3$)			1.01	0.98–1.03	0.99	0.95–1.02
Quartiles and 90th percentile						
<66.20 $\mu g/m^3$§	239	612	1		1	
≥66.20 to <87.60 $\mu g/m^3$	270	581	1.16	0.91–1.47	1.07	0.83–1.40
≥87.60 to <110.30 $\mu g/m^3$	259	593	1.00	0.79–1.27	0.90	0.67–1.19
≥110.30 to <129.10 $\mu g/m^3$	151	360	0.92	0.70–1.21	0.80	0.58–1.12
≥129.10 $\mu g/m^3$	123	218	1.21	0.89–1.66	0.95	0.64–1.39

Estimated time weighted average air pollution exposure 21–30 years before end of follow-up.
* Estimate obtained when only one pollutant was entered into the regression model.
† Estimate obtained when the corresponding variable for the other pollutant (SO_2 or NO_2) was entered separately into the same regression model as a confounder. For example, point estimates 1.15 (NO_2) and 0.99 (SO_2) for the continuous air pollution variables are obtained from the same model, and similarly for the categorical variable results.
‡ Adjusted for age, selection year, smoking, radon, socioeconomic grouping, occupational exposure to diesel exhaust, other combustion products and asbestos and employment in risk occupations.
§ Referent category.

TABLE 5. Relative Risk of Lung Cancer (and 95% Confidence Interval) According to Level of Individual Smoking Habits and Exposure to Traffic-Related NO_2 (as an Indicator of Air Pollution from Road Traffic) 20 Years Previously

Exposure to NO_2 from Road Traffic*		Never-Smoker	Former Smoker	Current Smoker (Average Consumption, Cigarettes/Day) 1–10	11–20	21 or More
Below 90th percentile (29.3 $\mu g/m^3$)	RR†	1	6.31	8.81	18.8	38.7
	95% CI	(ref)	4.25–9.38	5.76–13.5	12.6–28.2	25.1–59.6
Cases/controls		30/629	238/774	129/288	307/331	218/121
Above 90th percentile (29.3 $\mu g/m^3$)	RR†	1.68	9.95	12.0	27.9	28.8
	95% CI	0.67–4.19	5.71–17.3	5.60–25.7	15.3–51.0	13.9–59.6
Cases/controls		6/76	35/70	14/25	41/32	24/18
RR and 95% CI within smoking stratum	RR†	1.68	1.58	1.36	1.48	0.74
	95% CI	0.67–4.19	1.01–2.45	0.68–2.74	0.90–2.44	0.38–1.45

* Estimated time weighted 10-year average exposure lagged 20 years, *ie,* exposure 21–30 years before end of follow-up.
† Adjusted for age, selection year, smoking, radon, socioeconomic grouping, occupational exposure to diesel exhaust, other combustion products and asbestos and employment in risk occupations.

using both control groups. For the continuous variable, the estimates were 1.090 and 1.109, respectively, as compared with 1.096 (95% CI = 0.97–1.23). Thus, both control groups appeared to produce valid and equivalent results and were combined in the analyses.

Confounding from smoking seemed adequately controlled with the categorical variable, with only minor additional effect of adding continuous variables for average amount among current smokers and time since quitting among former smokers. A continuous variable for duration of smoking had no further effect on confounding control, probably because little correlation of air pollution exposure with smoking duration remained after stratification for age in 5-year intervals, smoking dose and subdivision of smokers into current and former smokers. A minor positive confounding effect by smoking included alone in the models tended to be balanced by minor negative confounding when adding the other risk factors.

Discussion

This study suggests an increased risk of lung cancer from traffic-related air pollution, assessed by individual annual estimates of traffic-related ambient NO_2 concentrations at the place of residence over a 30-year period, based on emission data and dispersion modeling. The clearest results were found for a time window covering the first of the three investigated exposure decades, *ie*, approximately 20 years in the past, which points to a considerable latency period. No effect was discernible for SO_2 related to residential heating, neither for long-term average levels, nor for past time windows. This finding appears somewhat paradoxical, as SO_2 levels were high in the past and NO_2 levels low, whereas in recent years SO_2 levels have decreased and NO_2 levels increased appreciably. Despite these contrasting temporal trends, however, the estimated exposures to heating-related SO_2 and traffic-related NO_2 showed reasonably high correlation, mainly due to geographical covariation. Nonetheless, traffic-related NO_2 rather than heating-related SO_2 was consistently the stronger risk indicator, with a suggestion of a 20-year latency period, a pattern that would seem to argue against a spurious association.

The controls in this study were selected from population registers with complete coverage of the study base from which the cases emanated. The response rate was high, over 85% among both cases and controls. Differential misclassification of air pollution exposure between cases and controls is not likely, since residential data on street address and years are unlikely to be affected by differential reporting bias, data was collected from several sources to obtain complete residential histories for virtually all subjects, and air pollution modeling is independent of case-control status. Non-differential misclassification, on the other hand, is probable and would tend to bias estimates for continuous variables and the top category of categorical variables toward the null.[21] The stronger effect seen in the time window analysis with 20-year lag suggests the possibility of decreased misclassification of biologically relevant exposure when an appropriate time window is specified. Nonetheless, the exposure indicators used in this study are still likely to be subject to non-systematic measurement error if they do not exactly correspond to the "true" exposure but are proxies for one or several components of the complex air pollution mix. Notwithstanding, a major strength of the present study lies in the long-term air pollution exposure assessment, which was based on detailed historical emission data and was performed individually for a 30-year residence period for each subject. Misclassification of true individual exposure is thus likely to be less serious than in many previous studies with cruder, non-individual exposure assessment. Furthermore, the emission data allowed us to partition exposure according to sources and use source-specific NO_2-levels as an indicator of traffic-related air pollution and source-specific SO_2 as an indicator of air pollution from residential heating. The individual exposure contrast appears to have been sufficient to evaluate variations in risk - the ratio between the 90th and 25th percentiles was 2.0 to 2.3 for NO_2 and 1.9 to 2.0 for SO_2 (Tables 3 and 4), and the 30-year average ranged 11-fold for NO_2 and almost 18-fold for SO_2.

Expected relative risks for lung cancer were found for smoking[7,23] and radon,[8,24] and increased RRs were obtained for some well-known and suspected occupational risk factors, suggesting that questionnaire data were of good quality. Detailed results regarding occupational exposure are published elsewhere.[6] In crude analyses, protective effect estimates were obtained for vegetable and fruit consumption, but were no longer clearly apparent after detailed adjustment for other known risk factors. This confounding may partly reflect inadequate dietary reporting from proxies, leading to misclassification of these variables. The dietary variables did not confound the relation between air pollution and smoking. It is possible that overall dietary differences in our data, and possible confounding of air pollution associations, was described better by the socioeconomic and occupational variables. For the effect associated with traffic-related NO_2, minor positive confounding from smoking tended to be balanced mainly by negative confounding when adding the other exposures. The degree of confounding was modest. Thus, although imprecision in measuring confounders may limit confounding control, residual confounding of importance seems unlikely in this study.

Not many studies of ambient air pollution and lung cancer risk have investigated several pollutant measures and few have considered both NO_2 and SO_2. Consistent with our results, two ecological studies have suggested that NO_2 rather than SO_2 is associated with regional differences in lung cancer mortality or incidence.[25,26] Similarly, a case-control study suggested that nitrogen oxides and carbon monoxide (city center, largely traffic-related), or ozone and particulates (incinerator area) were more likely to be responsible for the increased risk found in that study than SO_2 (iron foundry area).[27,28] In a U.S. cohort study conducted among Seventh-Day Adventists in California, a strong relation for lung cancer incidence and mortality to 20-year averages of respirable particles (PM_{10}) was observed among men; among women it was weaker.[29,30] Associations were similar also for ozone and SO_2 among men and appeared stronger for SO_2 among women. The gender differences appeared to be partially due to differences in exposure, mainly that males spent more time outdoors, particularly in the summer.[29,30] For NO_2 exposure, a weak relation to lung cancer incidence was observed in one-pollutant models (*eg*, RR 1.5, 95% CI = 0.7–3.1 per 1.98 ppb NO_2 among men), and slightly stronger effects on lung cancer mortality (RR 1.8, 95% CI = 0.9–3.6 among men and 2.8, 1.1–6.9 among women, per 1.98 ppb NO_2). These estimates weakened further when other pollutants, including SO_2, were introduced into the models. In the U.S. Six Cities study, the risk gradient across the six cities was more strongly associated with fine and sulfate particulate levels than with either SO_2 and NO_2 levels; the two latter were similarly correlated with risk.[4]

Earlier studies used quantitative or semi-quantitative data on measured total ambient air pollution levels, whereas our study uses source-specific contributions from road traffic and residential heating emissions to population NO_2 and SO_2 exposure, respectively. If other emission sources are important in other localities, total NO_2 and SO_2 are likely to have a different interpretation as proxies for air pollution exposures. Furthermore, the use of fixed site monitors, as in the two cohort studies mentioned above, is likely to entail important non-differential misclassification of exposure, in particular for gaseous pollutants, such as SO_2 and NO_2, where local variation in emissions may produce sizeable variations in exposure levels.

When a restriction to NO_x/NO_2 from road traffic is made, as in this study, it is likely to represent not only traffic-related NO_x/NO_2 emissions but also may be a good proxy for other components of vehicle exhausts, including components of diesel exhaust and possibly fine or ultrafine particles, which have been suggested to be particularly important for mortality. For example, a study from Finland in an area where traffic is a main source of pollutants found correlation coefficients of 0.55–0.94 between NO_2 and various particulate measures including PM_{10}, black smoke and number concentrations of fine and ultra-fine particles.[31] We were not able to make direct analyses of particulate air pollution in this study because of lack of historical measurements, past emission data and validated dispersion models for particulates.

Interestingly, our study gives evidence for lung cancer risk related to several combustion sources, smoking being by far the strongest risk factor. In addition, we found an increased risk for occupational diesel exposure and occupational exposure to other combustion products,[6] providing some support for the relation with traffic-related air pollution reported here.

Lag or induction times for an effect of air pollution on lung cancer risk have not often been considered. An ecological study in an area with very low smoking rates investigated the effect of opening a steel mill that became the major air pollution source and found increased lung cancer mortality rates within 15 years.[32] Two case-control studies found increased risks associated with air pollution indices at the last place of residence, but since the average duration of residence was 30 years or more, these indices may represent both recent and long-term exposure.[27,33] Another case-control study suggested a stronger effect by ambient air pollution when allowing for a latency period of 20 years than when lifetime exposure was considered.[34] Most other case-control studies did not investigate this aspect of exposure in detail.[1]

Of the approximately 10 cohort studies on ambient air pollution and lung cancer, the majority are older studies using an urban/rural exposure contrast.[1] Individual estimates of air pollution exposure were only made in one study, based on interpolation from fixed site monitoring stations.[3,29,30,35] Most cohort studies observed increased risk of lung cancer in the order of 1.5, surprisingly consistent and similar to the case-control studies.[1] Two recent U.S. studies with aggregate measured air pollution data suggest that the risk may be associated with fine or sulfate particulates.[45] In the third study, with individual exposure estimates, an effect of particulates, as well as ozone, was seen mainly in males, whereas a strong effect of SO_2 was seen in both genders.[29,30] NO_2 showed less of an association. One often-emphasized advantage of cohort studies is that because exposure information is collected before disease occurrence, differential bias in the exposure assessment is very unlikely. This advantage does not really apply in relation to our case-control study, however. Detailed exposure assessment using the methodology we have employed is unlikely to be affected by case-control status and represents a substantial improvement over most previous attempts to estimate long-term exposure to air pollution for individuals.

Some previous studies have suggested a multiplicative interaction between air pollution exposure and smoking, while others have been more consistent with an additive relation.[36] Our results are more compatible with a multiplicative interaction, except among heavy smokers, where no clear effect of traffic-related air pollution was evident. Similar weaker effects among heavy smokers have been observed for occupational arsenic[37] and residential radon[38,39] exposure. Possible explanations include a thickening of the bronchial mucosa,[40] a selection bias similar to the "healthy worker survivor effect" for maintaining high tobacco consumption, or chance.

Since exposure is widespread, the public health impact of a 50% increase in lung cancer risk among heavily exposed in the general population from traffic-related air pollution, as suggested by this study, may be important, and lower risk increases at more common moderate exposures potentially play a large role, too. An attributable risk calculation based on exposure above the 25th percentile suggests that the proportion of lung cancer among smoking and non-smoking males 40–75 years old in Stockholm County related to traffic-related air pollution exposure 20 years earlier could be as high as 10%.

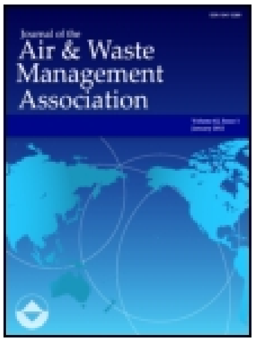
Acknowledgments

We thank Tage Jonsson and Malin Pettersson for development of the retrospective emission databases, and Camilla Bengtsson, Anna Boberg, Eva-Britt Gustavsson, Marcus Hugosson, Elin Junghahn, Ulla Klinga, Cecilia Rudengren, Patrik Schéele, Ewa Skarke, Agneta Wahlbom and Kerstin Åström for assistance with data collection and analyses.

References

1. Katsouyanni K, Pershagen G. Ambient air pollution exposure and cancer. Cancer Causes Control 1997;8:284–291.
2. Cohen AJ, Pope CA. Lung cancer and air pollution. Environ Health Perspect 1995;103(suppl 8):219–224.
3. Abbey DE, Lebowitz MD, Mills PK, Petersen FF, Beeson WL, Burchette RJ. Long-term ambient concentrations of particulates and oxidants and development of chronic disease in a cohort of nonsmoking California residents. Inhal Toxicol 1995;7:19–34.
4. Dockery DW, Pope CA 3d, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG, Jr., Speizer FE. An association between air pollution and mortality in six U. S. cities. N Engl J Med 1993;329:1753–1759.
5. Pope CA 3d, Thun MJ, Namboodiri MM, Dockery DW, Evans JS, Speizer FE, Heath CW, Jr. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. Am J Respir Crit Care Med 1995;151:669–674.
6. Gustavsson P, Jakobsson R, Nyberg F, Pershagen G, Järup L, Schéele P. Occupational exposure and lung cancer risk - a population-based case-referent study in Sweden. Am J Epidemiol (in press).
7. Carstensen JM, Pershagen G, Eklund G. Mortality in relation to cigarette and pipe smoking: 16 years' observation of 25,000 Swedish men. J Epidemiol Community Health 1987;41:166–172.
8. Pershagen G, Åkerblom G, Axelson O, Clavensjö B, Damber L, Desai G, Enflo A, Lagarde F, Mellander H, Svartengren M, Swedjemark GA. Residential radon exposure and lung cancer in Sweden. N Engl J Med 1994;330: 159–164.
9. Bellander T, Järup L, Berglind N, Gustavsson P, Jonson T, Nyberg F, Pershagen G. Using Geographic Information System techniques to assess individual historical exposure to air pollution in a case-control study of lung cancer in Stockholm. Stockholm, Sweden: Miljömedicinska enheten, Stockholms läns landsting [Department of Environmental Health, Stockholm County Council], in press.
10. MapInfo Professional (TM) User's Guide. Troy, New York: MapInfo Corporation, 1995.
11. Tätort 2000 Computerized geographical database of Swedish urban areas. Stockholm, Sweden: Kartcentrum, Lantmäteriverket, National Land Survey of Sweden, 1996.
12. Ekström A, Hadenius A, Jonson T. Emissionsdatabas 93 - en dokumentation (Emission database 93 - a documentation) (Swedish). Report 2:95. Stockholm, Sweden: Stockholm Air Quality and Noise Analysis, 1995; see also http://www.slb.mf.stockholm.se/.
13. Swedish Meteorological and Hydrological Institute. Airviro user documentation. Norrköping, Sweden: SMHI, 1997.
14. Swedish Meteorological and Hydrological Institute. Technical description of the dispersion models, Indic Airviro. Norrköping, Sweden: SMHI, 1993.
15. Nordisk yrkesklassificering (Nordic standard occupational classification) (Swedish). Stockholm, Sweden: Arbetsmarknadsstyrelsen (Swedish National Labour Market Board), 1983.
16. Boffetta P, Kogevinas M, Simonato L, Wilbourn J, Saracci R. Current perspectives on occupational cancer. Int J Occup Environ Health 1995;1: 315–325.
17. Ahrens W, Merletti F. A standard tool for the analysis of occupational lung cancer in epidemiological studies. Int J Occup Environ Health 1998;4:236–240.
18. Socioekonomisk indelning (Swedish socioeconomic classification) (Swedish). Stockholm, Sweden: SCB (Statistics Sweden), 1983.
19. Yrkesklassificeringar i FoB 85 enligt Nordisk yrkesklassificering (NYK) och Socioekonomisk indelning (SEI): alfabetisk version [Occupations in population and housing census 1985 (FoB 85) according to Nordic standard occupational classification (NYK) and Swedish socio-economic classification (SEI): alphabetical version] (Swedish). Stockholm, Sweden: SCB (Statistics Sweden), 1989.
20. Checkoway H, Pearce N, Hickey JL, Dement JM. Latency analysis in occupational epidemiology. Arch Environ Health 1990;45:95–100.
21. Rothman KJ, Greenland S. Modern Epidemiology. 2nd ed. Philadelphia: Lippincott-Raven Publishers, 1998.
22. StataCorp. Stata Statistical Software: Release 5.0. College Station, TX: Stata Corporation, 1997.
23. International Agency for Research on Cancer. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. vol 38. Tobacco Smoking. Lyon: International Agency for Research on Cancer, 1986.
24. Lubin JH, Boice JDJ. Lung cancer risk from residential radon: meta-analysis of eight epidemiologic studies. J Natl Cancer Inst 1997;89:49–57.
25. Choi KS, Inoue S, Shinozaki R. Air pollution, temperature, and regional differences in lung cancer mortality in Japan. Arch Environ Health 1997; 52:160–168.
26. Tango T. Effect of air pollution on lung cancer: a Poisson regression model based on vital statistics. Environ Health Perspect 1994;102(suppl 8):41–45.
27. Barbone F, Bovenzi M, Cavallieri F, Stanta G. Air pollution and lung cancer in Trieste, Italy. Am J Epidemiol 1995;141:1161–1169.
28. Biggeri A, Barbone F, Lagazio C, Bovenzi M, Stanta G. Air pollution and lung cancer in Trieste, Italy: spatial analysis of risk as a function of distance from sources. Environ Health Perspect 1996;104:750–754.
29. Beeson WL, Abbey DE, Knutsen SF. Long-term concentrations of ambient air pollutants and incident lung cancer in California adults: Results from the AHSMOG study. Review. Environ Health Perspect 1998;106:813–822.
30. Abbey DE, Nishino N, McDonnell WF, Burchette RJ, Knutsen SF, Beeson WL, Yang JX. Long-term inhalable particles and other air pollutants related to mortality in nonsmokers. Am J Respir Crit Care Med 1999;159:373–382.
31. Pekkanen J, Timonen KL, Ruuskanen J, Reponen A, Mirme A. Effects of ultrafine and fine particles in urban air on peak expiratory flow among

children with asthmatic symptoms. Environ Res 1997;74:24–33.
32. Archer VE. Air pollution and fatal lung disease in three Utah counties. Arch Environ Health 1990;45:325–334.
33. Jedrychowski W, Becher H, Wahrendorf J, Basa-Cierpialek Z. A case-control study of lung cancer with special reference to the effect of air pollution in Poland. J Epidemiol Community Health 1990;44:114–120.
34. Jockel KH, Ahrens W, Wichmann HE, Becher H, Bolm-Audorff U, Jahn I, Molik B, Greiser E, Timm J. Occupational and environmental hazards associated with lung cancer. Int J Epidemiol 1992;21:202–213.
35. Mills PK, Abbey DE, Beeson WL, Petersen F. Ambient air pollution and cancer in California Seventh-Day Adventists. Arch Environ Health 1991; 46:271–280.
36. Pershagen G, Simonato L. Epidemiological evidence on outdoor air pollution and cancer. In: Tomatis L, ed. Indoor and Outdoor Air Pollution and Human Cancer. Berlin: Springer-Verlag, 1993;135–148.
37. Järup L, Pershagen G. Arsenic exposure, smoking, and lung cancer in smelter workers—a case-control study [published erratum appears in Am J Epidemiol 1992;136:1174]. Am J Epidemiol 1991;134:545–551.
38. Svensson C, Pershagen G, Klominek J. Lung cancer in women and type of dwelling in relation to radon exposure. Cancer Res 1989;49:1861–1865.
39. Axelson O, Sundell L. Mining, lung cancer and smoking. Scand J Work Environ Health 1978;4:46–52.
40. Walsh PJ. Radiation dose to the respiratory tract of uranium miners—a review of the literature. Environ Res 1970;3:14–36.



Journal of the Air & Waste Management Association

ISSN: 1096-2247 (Print) 2162-2906 (Online) Journal homepage: http://www.tandfonline.com/loi/uawm20

Health benefits of air pollution abatement policy: Role of the shape of the concentration–response function

C. Arden Pope III, Maureen Cropper, Jay Coggins & Aaron Cohen

TECHNICAL PAPER

Health benefits of air pollution abatement policy: Role of the shape of the concentration–response function

C. Arden Pope III,[1,*] Maureen Cropper,[2] Jay Coggins,[3] and Aaron Cohen[4]

[1]*Department of Economics, Brigham Young University, Provo, UT, USA*

[2]*Department of Economics, University of Maryland, College Park, MD, USA*

[3]*Department of Applied Economics, University of Minnesota, St Paul, MN, USA*

[4]*Health Effects Institute, Boston, MA, USA*

[*]*Please address correspondence to: C. Arden Pope III, PhD, Department of Economics, Brigham Young University, 142 FOB, Provo, UT 84602, USA; e-mail: cap3@byu.edu*

There is strong evidence that fine particulate matter (aerodynamic diameter <2.5 μm; $PM_{2.5}$) air pollution contributes to increased risk of disease and death. Estimates of the burden of disease attributable to $PM_{2.5}$ pollution and benefits of reducing pollution are dependent upon the shape of the concentration–response (C-R) functions. Recent evidence suggests that the C-R function between $PM_{2.5}$ air pollution and mortality risk may be supralinear across wide ranges of exposure. Such results imply that incremental pollution abatement efforts may yield greater benefits in relatively clean areas than in highly polluted areas. The role of the shape of the C-R function in evaluating and understanding the costs and health benefits of air pollution abatement policy is explored. There remain uncertainties regarding the shape of the C-R function, and additional efforts to more fully understand the C-R relationships between $PM_{2.5}$ and adverse health effects are needed to allow for more informed and effective air pollution abatement policies. Current evidence, however, suggests that there are benefits both from reducing air pollution in the more polluted areas and from continuing to reduce air pollution in cleaner areas.

Implications: Estimates of the benefits of reducing $PM_{2.5}$ air pollution are highly dependent upon the shape of the $PM_{2.5}$-mortality concentration-response (C-R) function. Recent evidence indicates that this C-R function may be supralinear across wide ranges of exposure, suggesting that incremental pollution abatement efforts may yield greater benefits in relatively clean areas than in highly polluted areas. This paper explores the role of the shape of the C-R function in evaluating and understanding the costs and health benefits of $PM_{2.5}$ air pollution abatement.

Introduction

There is a large and growing literature that provides compelling evidence that air pollution contributes substantially to adverse health effects (U.S. Environmental Protection Agency [EPA], 2009; Pope and Dockery, 2006; Brook et al., 2010). The Global Burden of Disease 2010 collaboration estimated that the number of deaths attributable to ambient particulate matter air pollution, $PM_{2.5}$ (particulate matter with an aerodynamic diameter <2.5 μm), and household air pollution from solid fuels were approximately 3.2 and 3.5 million in 2010, respectively (Lim et al., 2012). These estimates, especially in global regions with the highest concentrations of ambient $PM_{2.5}$, were dependent upon assumptions regarding the shape of the concentration-response (C-R) functions. Although current evidence suggests that the C-R function between $PM_{2.5}$ air pollution and mortality risk is approximately linear for a relatively narrow range at low levels of pollution (Dockery et al., 1993; Pope et al., 2002; Miller et al., 2007; Crouse et al., 2012), recent research suggests that the C-R function is likely to be supralinear (concave) for wide ranges that include very high levels of exposure (Pope et al., 2009, 2011; Burnett et al., 2014). Even for lower concentrations observed in North America, the possibility of supralinearity has been suggested (Krewski et al., 2009; Crouse et al., 2012). Such results appear to imply that a given incremental reduction in concentrations will yield greater benefits in relatively clean areas than in the most highly polluted areas (Goodkind et al., 2014). Such findings may seem counterintuitive and even ethically unappealing because they appear inconsistent with a reasonable public policy objective to clean up the most polluted areas and protect populations most at risk. The objective of this paper is to explore the role of the shape of the C-R function in evaluating and understanding the costs and health benefits of air pollution abatement policy.

Traditional Conceptual Framework

A traditional economic theoretic framework to evaluate pollution abatement policy is illustrated in Figure 1. The

Journal of the Air & Waste Management Association, 65(5):516–522, 2015. ISSN: 1096-2247 print

DOI: 10.1080/10962247.2014.993004 Submitted September 29, 2014; final version submitted November 18, 2014; accepted November 19, 2014.

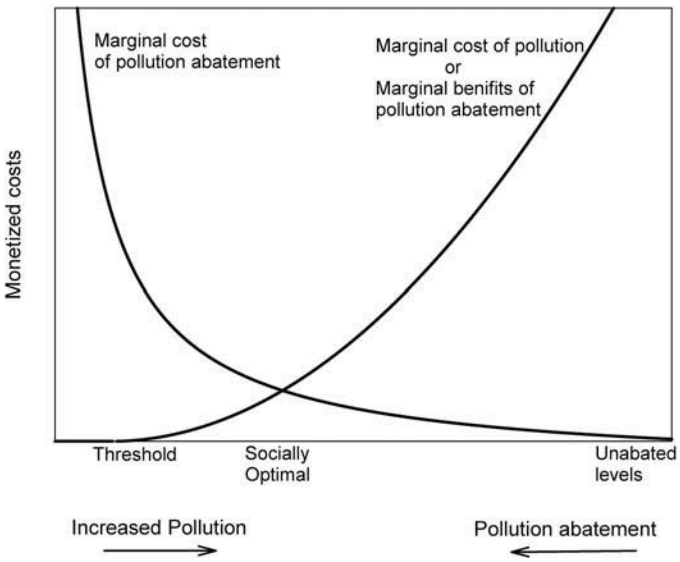


Figure 1. Traditional conceptual framework for economic analysis of marginal costs versus marginal benefits.

horizontal axis of this figure represents levels of pollution. Going from left to right indicates greater levels of pollution. Levels of pollution at the extreme far right of the axis are levels that would occur with no restrictions on pollution and no effort devoted to pollution abatement. Moving along the horizontal axis from right to left indicates pollution abatement or reduced pollution. At any given time and place, it is presumed that there will be some maximum level of pollution where there are no benefits to polluters from additional polluting. An unregulated polluting sector may be expected to pollute at this level, avoiding entirely any expenditure on abatement. It is also presumed that high pollution levels continue to occur even though, at least initially, pollution abatement would likely have relatively low cost. That is, the marginal (or incremental) cost of pollution abatement is low for the inexpensive and effective abatement strategies that will be adopted initially. However, further incremental efforts to abate air pollution results in ever-rising marginal abatement costs. Figure 1 presents a marginal cost of pollution abatement curve that illustrates that the marginal (or incremental) costs of pollution abatement rise as the air gets cleaner and it becomes increasingly difficult to obtain more pollution abatement and cleaner air.

Figure 1 also presents a traditional conceptualization of a marginal benefit of abatement curve. This curve represents the marginal (or incremental) benefits of additional air pollution abatement and is based on two key assumptions: (1) there is a threshold level of emissions below which pollution poses zero threat to human health; and (2) the marginal (or incremental) harm to health is more severe as pollution levels rise. This second assumption is fairly standard in the economics/policy literature and means that marginal abatement benefits fall as pollution levels fall. The marginal benefit of abatement curve also represents the marginal cost or marginal health damage of additional emissions, because the avoided costs of pollution are the benefits of pollution abatement. The marginal cost of pollution as illustrated in Figure 1, therefore, represents underlying assumptions that the largest marginal improvements in health come from pollution abatement at the highest levels of pollution. Put another way, the first unit of abatement is the most beneficial.

Figure 1 also helps illustrate various air pollution abatement policies. One possible approach would be a policy of laissez faire (let it be or do nothing). This policy might be welcomed by polluters who don't want to face costs of controlling their pollution, but in many cases it is far from optimal from society's perspective. Classic externality theory (and many real-world observations) suggests that this approach would result in excessive air pollution. If there is free unrestricted access to use the ambient air as a place to emit pollutants, polluters have little or no incentive to control their pollution and will engage in polluting activities as long as there are positive marginal returns to these activities. Because the costs of pollution abatement are largely borne by polluters, but the benefits of pollution abatement (avoided health costs) are dispersed more broadly across society, there are few incentives to abate air pollution. A second policy approach is to restrict air pollution levels at or below the threshold level where there are no or minimal health effects. The U.S. Clean Air Act implicitly assumes threshold levels for some pollutants (so-called criteria pollutants) and requires that national ambient air quality standards be set that "are requisite to protect the public health" with "an adequate margin of safety" (Clean Air Act Section 109(b)(1) [or 42 U.S.C. 7409]). There are two obvious difficulties with this policy approach. First, there may be no clearly identifiable threshold. Second, reducing air pollution to some very low threshold level may result in excessively high marginal costs of pollution abatement.

Economists define a socially optimal policy as one that maximizes total net benefits (i.e., total benefits minus total costs). As illustrated in Figure 1, more pollution abatement contributes to higher social welfare as long as the marginal costs of pollution abatement are less than the marginal benefits of abatement. The socially optimal level of air pollution occurs where the marginal benefits of abatement and the marginal cost of abatement are equal. We do not discuss alternative policy tools to reach this optimal level of pollution (e.g., regulations, emission taxes, or tradable pollution permits) in detail. The traditional framework illustrated in Figure 1 is appealing because it provides, at least conceptually, an approach to identifying socially optimal levels of pollution and suggests cleaning up the most polluted areas, which would provide protection to those who are most at risk.

How Research Informs Marginal Benefit Analysis

Over the last few decades, research on the health effects of air pollution has provided much additional information regarding the marginal costs of air pollution i.e. the marginal benefits of pollution abatement. It suggests that the assumptions embedded in Figure 1 may not be fully valid. Figure 2a

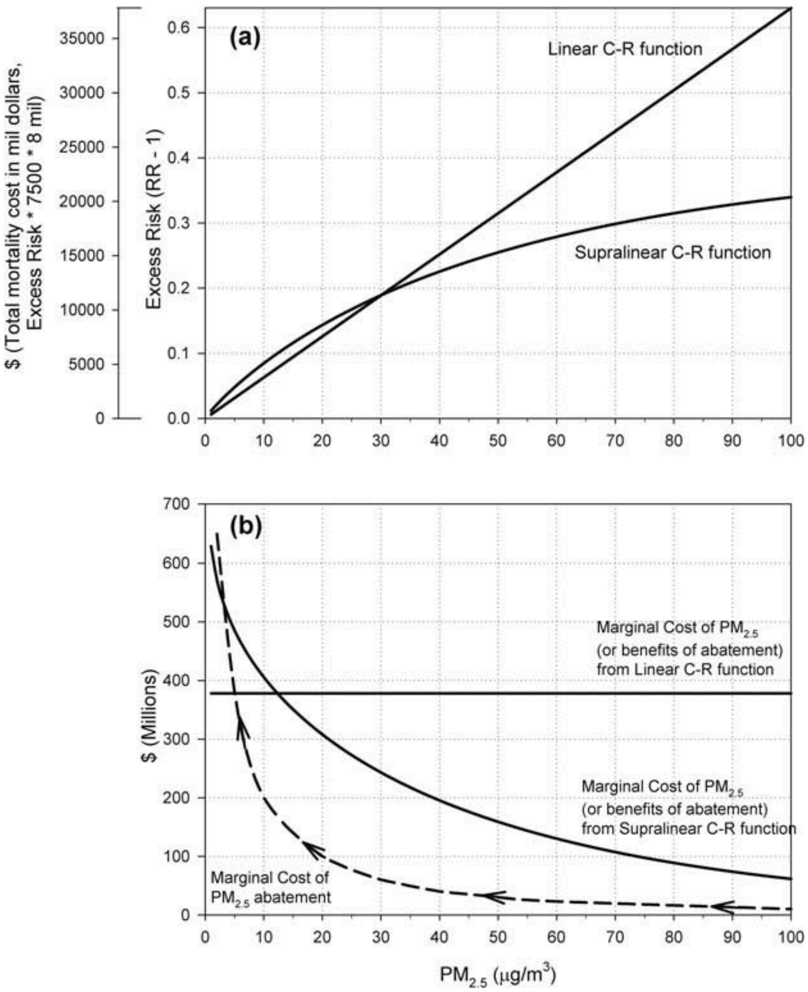


Figure 2. Stylized analysis of pollution abatement for linear and supralinear C-R functions.

provides an illustration of two alternative C-R functions, one linear and the other supralinear. Figure 2b shows the corresponding marginal benefit of abatement curves (solid) as well as an illustrative marginal cost curve (dashed). These marginal benefit curves are more empirically based on recent research results. A key issue and important issue illustrated in Figure 2b is that the marginal benefits associated with a supralinear C-R function are *increasing* with increased abatement. The marginal benefits due to initial abatement activities are quite small, whereas the marginal benefits due to the last unit of abatement, taking concentrations down to the cleanest practicable level, are quite high. Because C-R functions and cost structures are not known with certainty and because they are also different across settings and times, Figure 2 remains stylistic and is used only for more realistic illustration. There remains some uncertainty regarding the health effects of air pollution, but the relationships depicted in Figure 2 illustrate at least four general fundamental research findings that are relevant to a contemporary exploration of the health benefits of air pollution abatement policy.

First, fine particulate matter air pollution (particles with an aerodynamic diameter <2.5 μm, $PM_{2.5}$) is strongly and consistently associated with adverse health effects (EPA, 2009; Pope and Dockery, 2006; Brook et al., 2010). The horizontal axes in Figure 2 indicate $PM_{2.5}$ concentrations (in units of μg/m^3) ranging from 0 to 100. Multiple cities in China, India, and elsewhere have average concentrations of $PM_{2.5}$ that are approximately equal to or even exceed 100 μg/m^3 (Chen et al., 2012; Brauer et al., 2012).

Second, in terms of health costs, the most dominant health effect is the increased risk of all-cause and/or cardiovascular mortality associated with long-term chronic exposure to $PM_{2.5}$ (Dockery et al., 1993; Pope et al., 2002; Miller et al., 2007; Krewski et al., 2009; Brook et al., 2010; Crouse et al., 2012). Studies of the health costs of air pollution suggest that approximately 90% of the total health costs are associated with increased mortality (EPA, 2011).

Third, although there remains some uncertainty regarding the shape of the C-R function, at ranges of pollution levels common to the United States, Canada, and Western Europe (generally $PM_{2.5}$ concentrations between 5 and 30 μg/m^3), the estimated $PM_{2.5}$-mortality C-R functions tend to be near linear with no discernible thresholds for $PM_{2.5}$ exposures (Dockery et al., 1993; Pope et al., 2002; Crouse et al., 2012), suggesting that the marginal benefit of reductions in $PM_{2.5}$ concentrations is constant or flat in these areas. In Figure 2a, the linear C-R function reflects this assumed linearity and projects it out throughout the full range of exposure. A recent meta-analytic review of the association between long-term exposure to $PM_{2.5}$ and all-cause mortality provided an overall pooled estimate of approximately 6% excess risk of all-cause mortality per 10 $\mu g/m^3$ increase in $PM_{2.5}$ (Hoek et al., 2013). The C-R functions illustrated in Figure 2a approximately reflect this pooled estimate for $PM_{2.5}$ concentrations below 30 $\mu g/m^3$. The excess risk (ER) for the linear C-R function is calculated as

$$ER = 0.0063 \times (PM_{2.5}) \quad (1)$$

Fourth, there is some evidence, even in the U.S. and Canadian studies, of a supralinear C-R function where the marginal (or incremental) effects of exposure actually decline with increased exposure (Krewski et al., 2009; Crouse et al., 2012). Recent analyses that integrate information from studies of $PM_{2.5}$ ambient air pollution, secondhand cigarette smoke exposure, and active cigarette smoking provide further evidence that the exposure-response function is not linear throughout the range of potential exposures (Pope et al., 2009, 2011; Burnett et al., 2014), but that it flattens out when exposure is extended to very high levels. The excess risk for the assumed supralinear C-R function illustrated in Figure 2 is calculated as

$$ER = 0.4\left\{1 - \exp\left[-0.03(PM_{2.5})^{0.9}\right]\right\} \quad (2)$$

This function is based on the functional form of the integrated risk function that was used for estimating the global burden of disease attributable to $PM_{2.5}$ (Burnett et al., 2014; Lim et al., 2012), but it is modified for illustrative purposes and appears to be approximately consistent with estimates of all-cause mortality in the United States (Krewski et al., 2009).

Stylized Analysis of Pollution Abatement

Figure 2 now allows us to illustrate a stylized analysis of pollution abatement that is reasonably consistent with the available air pollution research. We can also rescale (monetize) the ER from the C-R function in Figure 2a to approximately reflect the costs of excess mortality in a given population. Larger populations have more affected persons and, therefore, larger human health costs of pollution. The rescaling in Figure 2 assumes a population of one million people. We assume a baseline morality rate, with no pollution exposure, of 7500/million (although the baseline mortality rates can differ significantly across populations depending on age/health profiles and other competing risk factors). We also assign a value of a statistical life (VSL) equal to \$8 million. VSL represents the sum of what individuals would pay for reductions in their risk of dying that sum to saving one statistical life. VSL estimates are, therefore, dependent on incomes, preferences regarding risk trade-offs, and related factors. For example, if a policy reduced the risk of death over the coming year by 1 in 10,000 for each of 10,000 people, one statistical life would be saved. If people were willing to pay, on average, \$800 for a 1 in 10,000 risk reduction, the VSL would be \$8 million, a value consistent with recent labor market estimates of the VSL in the United States (Kniesner et al., 2014). This value is also comparable to VSL estimates used in a cost-benefit analysis conducted by the EPA (EPA, 2011).

The marginal cost of $PM_{2.5}$ curves in Figure 2b are the first derivatives (or slopes) of the C-R functions in Figure 2a scaled to reflect monetized costs of excess morality. The marginal cost of $PM_{2.5}$ from the linear C-R function is clearly constant throughout the range of exposure, whereas the marginal cost of $PM_{2.5}$ from the supralinear C-R function declines with increasing levels of exposure.

In the situation with constant or even declining marginal (or incremental) costs of pollution, does pollution abatement make sense, especially in highly polluted areas? It depends upon the marginal costs of pollution abatement relative to the marginal costs of pollution (the marginal benefits of reducing pollution). For example, in Figure 2b, the dashed line represents a possible marginal cost of abatement curve, where the marginal cost of abatement is low initially but rises as the air gets cleaner. Although the marginal benefit of $PM_{2.5}$ also rises as the air becomes cleaner, at high levels of pollution the marginal benefit of reducing pollution exceeds the marginal cost, implying that it is efficient to reduce pollution. The socially optimal level of pollution abatement is not reached until the marginal cost of abatement exceeds the marginal benefits of abatement (i.e., the avoided marginal costs of pollution). In Figure 2b, this occurs at about 5 $\mu g/m^3$ of $PM_{2.5}$, assuming the linear C-R function, and even less for the supralinear. Of course, it could turn out that pollution abatement is extremely expensive, so that the marginal cost of abatement curve shifts upward in the figure. If this is the case, marginal costs of pollution abatement may always exceed the marginal benefits and the optimal policy would be no abatement at all, but rather to accept the relatively less expensive health costs of air pollution.

More complicated situations can also arise. One example, not essential to this analysis, is a marginal benefit curve that slopes upward and is also steeper than marginal abatement costs, which can cause either zero abatement or maximal abatement to be optimal from society's perspective. This possibility can be of special interest when there is significant uncertainty in the cost of abatement.

Implications of a Supralinear C-R Function for Optimal Pollution Abatement in the United States

What are the implications of a supralinear C-R function for optimal pollution abatement? In a recent study using data from the United States, Goodkind et al. (2014) evaluated three air pollution abatement policies, comparing their performance when either a linear or a supralinear C-R function is the correct specification of the pollution-health relationship. Their analysis is based upon a synthetic model of a rectangular geographic region. In each of 600 25 km × 25 km spatial grid cells, population approximates the latest Census Bureau data for a section of the U.S. Midwest. Each cell contains a single source of primary $PM_{2.5}$, whose emissions disperse spatially according to a Gaussian plume model. The cost of abatement takes the usual shape, resembling that found in Figure 1.

The first of three abatement policies considered selects the socially optimal abatement level for each source—optimal in the sense that the combination leads to the maximum possible aggregate net benefits. The second is a uniform maximum concentration standard, resembling the National Ambient Air Quality Standards (NAAQS) but set so as to achieve the greatest possible net benefits among all uniform standards. The third is an emission tax paid by sources for each ton of pollution they emit.

The analysis of these policies is based upon a simulation exercise in which abatement for each source is set according to the policy rule in question. In each of 1000 runs, two elements of the model are randomized: the initial distribution of emissions across space and the parameters in the source-specific abatement cost functions. The two C-R functions are taken from table 11 in Krewski et al. (2009), which resemble the functional forms given in eqs 1 and 2 and depicted in Figure 2a.

In comparing the socially optimal policy to the uniform standard, Goodkind et al. (2014) find that for both C-R specifications, the optimal policy leads to lower emissions, lower resulting pollution concentrations, and greater net social benefits than the uniform standard. Under either policy, emissions and concentrations are lower and net benefits higher if the supralinear C-R function is correct than if the linear C-R function is correct. If the true health relationship is supralinear, then society should strive for much cleaner air.

In comparing the socially optimal policy to the emission tax, the same general comparative results are obtained. Once again, the optimal policy leads to lower emissions and concentrations and higher net social benefits than the alternative tax policy. And again, under either policy, the supralinear C-R function, if correct, leads to lower emissions, pollution concentrations, and higher net social benefits than if the linear function is correct.

These results suggest that understanding the curvature of the C-R function might be of critical importance in the formulation of clean-air policy. In particular, if the relationship between pollution and human health is supralinear, then the benefits to aggressive abatement in the United States could be much larger than otherwise thought.

A final set of findings provides a useful glimpse into the question of fairness or environmental justice. If the C-R function is linear, then reducing concentration by 1 $\mu g/m^3$ provides the same marginal health benefit everywhere. There is no intrinsic tension between cleaning the dirtiest places and achieving the greatest health gains for the greatest number. If, on the other hand, the C-R function is supralinear, then one must worry that a socially optimal policy will make the cleanest places cleaner, whereas those in dirty places see little improvement. As indicated by Figure 2a, the greatest incremental health gains are achieved where the air is already relatively clean.

The results of Goodkind et al. suggest that, in the United States, this concern may not be as great as expected, and the reason is found in the spatial nature of pollution and its dispersion across the landscape. Indeed, Gini coefficients (Marshall et al., 2014), indicating the degree of exposure inequality, differ very little for the various policy approaches. In all cases, inequality is reduced significantly relative to the initial situation, before the policy is imposed. The difference in Ginis for the two C-R functions is also quite small. This surprising result appears to be due to the way in which the large reductions called for in clean places under the supralinear C-R function led to large reductions in neighboring places. In short, because $PM_{2.5}$ disperses widely, cleaning the cleanest places means also cleaning dirty places.

Implications of a Supralinear C-R Function for Air Pollution Control Policies in India and China

Are the results obtained by Goodkind et al. (2014) likely to hold in countries such as India and China where pollution levels are much higher than in the United States? The slope of the supralinear C-R function, evaluated at the annual average $PM_{2.5}$ standard in the United States (12 $\mu g/m^3$), is actually slightly larger than the slope of the linear function in eq 1. It is at the air pollution levels observed in India and China that the slope of the C-R function may become much flatter, implying a smaller reduction in excess mortality for each $\mu g/m^3$ reduction in $PM_{2.5}$. A flatter C-R function does not, however, necessarily imply that the marginal benefits of a pollution control project will be lower in India or China than in the United States—or that the benefits of a project will fall short of the costs. We illustrate this by considering recent studies of the benefits and costs of installing flue-gas desulfurization units (scrubbers) on coal-fired power plants in India and China to reduce sulfur dioxide emissions and the associated $PM_{2.5}$.

The lives saved by installing a scrubber at a power plant are the product of the change in ambient $PM_{2.5}$ concentrations, the size of the exposed population, the baseline death rate in the exposed population, and the change in excess risk (the slope of the C-R function). The marginal benefits of the project are the product of lives saved times the VSL.

$$\text{Lives saved} = \Delta PM_{2.5} \times \text{Exposed population} \times \text{Baseline death rate} \times \Delta ER \tag{3a}$$

$$\text{Marginal benefits} = \text{Lives saved} \times \text{VSL} \tag{3b}$$

Holding the slope of the C-R function fixed, implementing the policy in a densely populated area will increase the marginal benefits of the policy. The value of these benefits will also be higher the more people are willing to pay to reduce risk of death (i.e., the higher the VSL), which should increase with income. Whether marginal benefits exceed the marginal costs also depends, of course, on the cost of installing and operating the scrubber. Given economies of scale, the marginal cost of reducing emissions is likely to be lower at larger power plants.

A recent study of the costs and benefits of retrofitting coal-fired power plants in India with flue-gas desulfurization units (Malik, 2013) suggests that this policy does pass the benefit-cost test, especially in densely populated areas. Retrofitting 72 coal-fired power plants with scrubbers would save lives at an average cost of 6 million Rs. (approximately $100,000) per life saved. The cost per life saved varies greatly across plants, from 1.56 million Rs. to 31.5 million Rs. depending on the size of the exposed population and the size of the plant. At the 30 largest plants, which account for two-thirds of the sulfur emissions generated, the cost per life saved varies from 1.56 to 14.7 million Rs. Bhattacharya et al. (2007) report a preferred VSL estimate of 1.3 million Rs. (2006 Rs.) based on a stated preference study of Delhi residents. Madheswaran's (2007) estimate of the VSL based on a compensating wage study of workers in Calcutta and Mumbai is approximately 15 million Rs. Shanmugam (2001) reports a much higher value (56 million Rs.) using data from 1990. Although published estimates of the VSL for India vary widely, studies suggest that retrofitting scrubbers indeed passes the benefit-cost test, in spite of the higher average $PM_{2.5}$ levels in India.

Partridge and Gamkhar (2010, 2012) examine the benefits and costs of installing a scrubber on a 1200-MW coal-fired power plant in each of 29 locations in China, which span the six regions of the Chinese electricity grid (Central, North, Eastern, Northeast, Northwest, and South). The health benefits of the scrubber are valued using a VSL for China of 1.3 million 2007 RMB (about $171,000 USD at market exchange rates), based on contingent valuation studies conducted in China. The authors also calculated the value of reductions in chronic bronchitis and hospital admissions, based on Aunan and Pan (2004); however, over 95% of the benefits were attributed to premature mortality. Results for the 29 plants are grouped by grid region. Benefits per MWhr of electricity generated are highest for plants in the Central, East, and North regions of China, which are also the most populous regions of the country. These benefits exceed the estimated cost per MWhr of scrubbing in the most populous region (the Central region), implying that scrubbers pass the benefit-cost test in that region. They are, however, less than half the cost of scrubbing in the least densely populated regions (the Northwest, Northeast, and South).

These examples suggest that even if a supralinear C-R function is correct, this does not necessarily imply that pollution abatement policies will fail to have health benefits greater than the costs in countries with exceptionally high pollution levels. The slope of the C-R function describes the percentage reduction in baseline deaths associated with a reduction in air pollution. Marginal benefits also depend on the size of the exposed population, baseline death rates, and the value attached to mortality risk reductions. This implies that considerable benefits could accrue from improving air quality in low- and middle-income countries such as China and India where population-weighted air pollution exposure has increased over the past 20 years and where, over that same interval, mortality from noncommunicable diseases affected by air pollution is increasing in their large and aging populations.

Conclusion

The traditional understanding of environmental policy, reflected in the language of the U.S. Clean Air Act, holds that the marginal health benefits associated with abatement become smaller as the air becomes cleaner. Recent research results, which suggest that the C-R function for $PM_{2.5}$ may in fact be supralinear at levels of air pollution prevalent in low- and middle-income countries such as China and India, suggest that the traditional understanding of policy may be incorrect. A supralinear C-R function, if correct, would imply that the percentage reduction in mortality per unit of abatement would be lower at the higher air pollution levels currently found in India and China than in the United States. This implies then that considerable improvements in air quality will be required to achieve substantial reductions disease burden. However, the marginal benefits associated with pollution control policies depend also upon the size of the exposed population, baseline death rates, and the value attached to reductions in mortality risks. Therefore, even incremental improvements could confer important public health benefits. This is the view embodied in the World Health Organization's (WHO) world air quality guidelines, which include interim targets in addition to the much lower air quality guideline itself (WHO, 2006).

The current epidemiologic evidence does not provide strong support for nonlinearity over the range of ambient air pollution in the world's cleanest places, e.g., the United States and Western Europe, although the shape of the mortality exposure-response for $PM_{2.5}$ at low levels is subject to some uncertainty. If future research were to strengthen the evidence in support supralinearity at low levels of pollution, tighter standards, at which the high marginal health benefits associated with achieving substantially lower concentrations are experienced, might be justified.

The estimation of benefits of pollution abatement is further complicated by the broad spatial dispersion of $PM_{2.5}$, its precursors, and related pollutants. Substantial air pollution abatement efforts focused on reducing pollution in highly polluted areas can result in significant improvements in air quality in other areas with relatively clean air. The supralinear C-R function suggests that there may be relatively high collateral benefits as a result of reduced dispersed pollution to other cleaner areas.

Given the toll imposed on human health by particulate pollution around the world, these questions are of great significance. At this point, there would appear to be benefits both from reducing air pollution in the most polluted places and continuing to reduce air pollution in the cleanest places as well, the uncertainties regarding the shape of the exposure-response relations notwithstanding. There is also a clear and compelling need for a more thorough understanding of the shape of the C-R function over the entire global range. This can come only with additional research, especially new, large epidemiologic studies with sufficient statistical power and precision to better characterize the shape of the exposure-response relations at the high and low ends of the global exposure distribution. Reducing the uncertainties in the current understanding of the C-R relationships between $PM_{2.5}$ and adverse health effects would allow more informed environmental policy decisions and warrants devoting further energy and resources to addressing these questions.

Acknowledgment

The views expressed in this article do not represent those of the Health Effects Institute or its sponsors.

References

Aunan, K., and X.-C. Pan. 2004. Exposure-response functions for health effects of ambient air pollution applicable for China—A meta-analysis. *Sci. Total Environ*. 329:3–16. doi:10.1016/j.scitotenv.2004.03.008

Bhattacharya, S., A. Alberini, and M.L. Cropper. 2007. The value of mortality risk reduction in Delhi, India. *J. Risk Uncertain*. 34:21–47. doi:10.1007/s11166-006-9002-5

Brauer, M., M. Amann, R.T. Burnett, A. Cohen, F. Dentener, M. Ezzati, S.B. Henderson, M. Krzyzanowski, R.V. Martin, R. Van Dingenen, et al. 2012. Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution. *Environ. Sci. Technol*. 46:652–660. doi:10.1021/es2025752

Brook, R.D., S. Rajagopalan, C.A. Pope III, J.R. Brook, A. Bhatnagar, A.V. Diez-Rouz, F. Holguin, Y. Hong, R.V. Luepker, M.A. Mittleman, et al. 2010. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation* 121:2331–2378. doi:10.1161/CIR.0b013e3181dbece1

Burnett, R.T., C.A. Pope III, M. Ezzati, C. Olives, S.S. Lim, S. Mehta, H.H. Shin, G. Singh, B. Hubbell, M. Brauer, et al. 2014. An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. *Environ. Health Perspect*. 122:397–403. doi:10.1289/ehp.1307049

Chen, R., H. Kan, B. Chen, et al. 2012. Association of particulate air pollution with daily mortality: The China Air Pollution and Health Effects Study. *Am. J. Epidemiol*. 175:1173–1181. doi:10.1093/aje/kwr425

Crouse, D.L., P.A. Peters, A. van Donkelaar, M.S. Goldbert, P.J. Villeneuve, O. Brion, S. Khan, D.O. Atari, M. Jerrett, C.A. Pope, III, et al. 2012. Risk of non-accidental and cardiovascular mortality in relation to long-term exposure to low concentrations of fine particulate matter: A Canadian national-level cohort study. *Environ. Health Perspect*. 120:708–714. doi:10.1289/ehp.1104049

Dockery, D.W., C.A. Pope III. X.P. Xu, J.D. Spengler, J.H. Ware, M.E. Fay, B. G. Ferris, and F.E. Speizer. 1993. An association between air pollution and mortality in six U.S. cities. *N. Engl. J. Med*. 329:1753–1759. doi:10.1056/NEJM199312093292401

Goodkind, A.L., J.S. Coggins, and J.D. Marshall. 2014. A spatial model of air pollution: The impact of the concentration-response function. *J. Assoc. Environ. Resour. Econ*. 1:451–479. doi:10.1086/678985

Hoek, G., R. Krishnan, R. Beelen, A. Peters, B. Ostro, B. Brunekreef, and J.D. Kaufman. 2013. Long-term air pollution exposure and cardio-respiratory mortality: A review. *Environ. Health*. 2013;12:43. doi:10.1186/1476-069X-12-43

Kniesner, T. J., W.K. Viscusi, and J.P. Ziliak. 2014. Willingness to accept equals willingness to pay for labor market estimates of the value of a statistical life. *J. Risk Uncertain*. 48:187–205. doi:10.1007/s11166-014-9192-1

Krewski, D., M. Jerrett, R.T. Burnett, R. Ma, E. Hughes, Y. Shi, M.C. Turner, C.A. Pope, III, G. Thurston, E.E. Calle, et al. 2009. *Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality*, 5–114, discussion 115–136. HEI Research Report 140. Boston, MA: Health Effects Institute.

Lim, S.S., T. Vos, A.D. Flaxman, G. Danaei, K. Shibuya, H. Adair-Rohani, M. Amann, H.R. Anderson, K.G. Andrews, M. Aryee, et al. 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: A systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 380: 2224–2260. doi:10.1016/S0140-6736(12)61766-8

Madheswaran, S. 2007. Measuring the value of statistical life: Estimating compensating wage differentials among workers in India. *Soc. Indic. Res*. 84:83–96. doi:10.1007/s11205-006-9076-0

Malik, K. 2013. Essays on energy and environment in India. Ph.D. dissertation, University of Maryland, College Park, Maryland.

Marshall, J.D., K.R. Zwor, and N.P. Nguyen. 2014. Prioritizing environmental justice and equality: Diesel particles in California's South Coast. *Environ. Sci. Technol*. 48:4063–4068. doi:10.1021/es405167f

Miller, K.A., D.S. Siscovick, L. Sheppard, J.H. Sullivan, G.L. Anderson, and J. D. Kaufman. 2007. Long-term exposure to air pollution and incidence of cardiovascular events in women. *N. Engl. J. Med*. 356:447–458. doi:10.1056/NEJMoa054409

Partridge, I., and S. Gamkhar. 2010. Estimation of health impacts of air pollution in China. http://www.webmeets.com/files/papers/WCERE/2010/911/Estimation%20of%20Health%20Impacts%20of%20Air%20Pollution%20in%20China.pdf (accessed August 21, 2014).

Partridge, I., and S. Gamkhar. 2012. A methodology for estimating health benefits of electricity generation using renewable technologies. *Environ. Int*. 39:103–110. doi:10.1016/j.envint.2011.10.003

Pope, C.A., III, R.T. Burnett, D. Krewski, M. Jerrett, Y.L. Shi, E.E. Calle, and M.J. Thun. 2009. Cardiovascular mortality and exposure to airborne fine particulate matter and cigarette smoke: Shape of the exposure-response relationship. *Circulation* 120:941–948. doi:10.1161/CIRCULATIONAHA.109.857888

Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G. D. Thurston. 2002. Lung cancer, cardiopulmonary mortality and long-term exposure to fine particulate air pollution. *JAMA* 287:1132–1141. doi:10.1001/jama.287.9.1132

Pope, C.A., III, R.T. Burnett, M.D. Turner, A. Cohen, D. Krewski, M. Jerrett, S.M. Gapstur, and M.J. Thun. 2011. Lung cancer and cardiovascular disease mortality associated with ambient air pollution and cigarette smoke: Shape of the exposure-response relationships. *Environ. Health Perspect*. 119:1616–1621. doi:10.1289/ehp.1103639

Pope, C.A., III, and D.W. Dockery. 2006. Critical review—Health effects of fine particulate air pollution: Lines that connect. *J. Air Waste Manage. Assoc*. 56:709–742. doi:10.1080/10473289.2006.10464485

Shanmugam, K.R. 2001. Self-selection bias in the estimates of compensating wage differentials for job risks in India. *J. Risk Uncertain*. 23:263–275.

U.S. Environmental Protection Agency. 2009. *Integrated Science Assessment for Particulate Matter (Final Report)*. EPA/600/R-08/139F. Washington, DC: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. 2011. *The Benefits and Costs of the Clean Air Act from 1990 to 2020 (Final Report—Rev A)*. Washington, DC: U.S. Environmental Protection Agency Office of Air and Radiation.

World Health Organization. 2006. *WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Global Update 2005*. Geneva, Switzerland: WHO Press.

About the Authors

C. Arden Pope III is the Mary Lou Fulton Professor of Economics at Brigham Young University at Provo, UT, USA.

Maureen Cropper is a distinguished university professor and chair of the Department of Economics at the University of Maryland in College Park, MD, USA, and is a senior fellow at Resources for the Future.

Jay Coggins is an associate professor in the Department of Applied Economics at the University of Minnesota in St. Paul, MN, USA.

Aaron Cohen is a principle scientist at the Health Effects Institute in Boston, MA, USA.

ONLINE FIRST

Traffic-Related Air Pollution, Particulate Matter, and Autism

Heather E. Volk, PhD, MPH; Fred Lurmann; Bryan Penfold; Irva Hertz-Picciotto, PhD; Rob McConnell, MD

Context: Autism is a heterogeneous disorder with genetic and environmental factors likely contributing to its origins. Examination of hazardous pollutants has suggested the importance of air toxics in the etiology of autism, yet little research has examined its association with local levels of air pollution using residence-specific exposure assignments.

Objective: To examine the relationship between traffic-related air pollution, air quality, and autism.

Design: This population-based case-control study includes data obtained from children with autism and control children with typical development who were enrolled in the Childhood Autism Risks from Genetics and the Environment study in California. The mother's address from the birth certificate and addresses reported from a residential history questionnaire were used to estimate exposure for each trimester of pregnancy and first year of life. Traffic-related air pollution was assigned to each location using a line-source air-quality dispersion model. Regional air pollutant measures were based on the Environmental Protection Agency's Air Quality System data. Logistic regression models compared estimated and measured pollutant levels for children with autism and for control children with typical development.

Setting: Case-control study from California.

Participants: A total of 279 children with autism and a total of 245 control children with typical development.

Main Outcome Measures: Crude and multivariable adjusted odds ratios (AORs) for autism.

Results: Children with autism were more likely to live at residences that had the highest quartile of exposure to traffic-related air pollution, during gestation (AOR, 1.98 [95% CI, 1.20-3.31]) and during the first year of life (AOR, 3.10 [95% CI, 1.76-5.57]), compared with control children. Regional exposure measures of nitrogen dioxide and particulate matter less than 2.5 and 10 μm in diameter ($PM_{2.5}$ and PM_{10}) were also associated with autism during gestation (exposure to nitrogen dioxide: AOR, 1.81 [95% CI, 1.37-3.09]; exposure to $PM_{2.5}$: AOR, 2.08 [95% CI, 1.93-2.25]; exposure to PM_{10}: AOR, 2.17 [95% CI, 1.49-3.16) and during the first year of life (exposure to nitrogen dioxide: AOR, 2.06 [95% CI, 1.37-3.09]; exposure to $PM_{2.5}$: AOR, 2.12 [95% CI, 1.45-3.10]; exposure to PM_{10}: AOR, 2.14 [95% CI, 1.46-3.12]). All regional pollutant estimates were scaled to twice the standard deviation of the distribution for all pregnancy estimates.

Conclusions: Exposure to traffic-related air pollution, nitrogen dioxide, $PM_{2.5}$, and PM_{10} during pregnancy and during the first year of life was associated with autism. Further epidemiological and toxicological examinations of likely biological pathways will help determine whether these associations are causal.

Arch Gen Psychiatry.
Published online November 26, 2012.
doi:10.1001/jamapsychiatry.2013.266

Author Affiliations are listed at the end of this article.

AUTISM SPECTRUM DISORDERS are a group of developmental disorders commonly characterized by problems in communication, social interaction, and repetitive behaviors or restricted interests.[1] Although the severity of impairment for the autism spectrum disorders varies across the spectrum (full syndrome autism being the most severe), the incidence rate of all autism spectrum disorders is now reported to be as high as 1 in 110 children.[2] Emerging evidence suggests that environment plays a role in autism, yet at this stage, only limited information is available as to what exposures are relevant, their mechanisms of action, the stages of development in which they act, and the development of effective preventive measures.

See related editorial

Recently, air pollution has been examined as a potential risk factor for autism. Using the Environmental Protection Agen-

Table 1. Spearman Correlations of Traffic-Related Air Pollution (TRP) and Regional Pollutants for 524 Children[a]

First Year of Life Estimates	All Pregnancy Estimates				
	TRP	$PM_{2.5}$	PM_{10}	Ozone	Nitrogen Dioxide
TRP	0.92[b]	0.36[c]	0.33[c]	−0.36[c]	0.60[c]
$PM_{2.5}$	0.25[d]	0.67[b]	0.77[c]	−0.11[c]	0.63[c]
PM_{10}	0.27[d]	0.84[d]	0.82[b]	0.13[c]	0.66[c]
Ozone	−0.31[d]	0.26[d]	0.27[d]	0.74[b]	−0.29[c]
Nitrogen dioxide	0.58[d]	0.60[d]	0.64[d]	−0.19[d]	0.89[b]

Abbreviations: $PM_{2.5}$, particulate matter less than 2.5 μm in aerodynamic diameter; PM_{10}, particulate matter less than 10 μm in aerodynamic diameter.
[a] All correlation measures were statistically significant ($P < .05$).
[b] Correlations of the same pollutant across time periods.
[c] Correlations across pollutants within pregnancy.
[d] Correlations across pollutants within the first year of life.

cy's dispersion-model estimates of ambient concentrations of hazardous air pollutants, Windham and colleagues[3] identified an increased risk of autism based on exposure to diesel exhaust particles, metals (mercury, cadmium, and nickel), and chlorinated solvents in Northern California census tracts. Additional research using dispersion-model estimates of hazardous air pollutants also reported associations between autism and air toxics at the birth residences of children from North Carolina and West Virginia.[4] These epidemiologic findings on autism are supported by additional research[5,6] describing other physical and developmental effects of air pollution due to prenatal and early life exposure. For example, high levels of air pollutants have been associated with poor birth outcomes, immunologic changes, and decreased cognitive abilities.[5,6]

Recently, we reported an association between the risk of autism and an early life residence within 309 m of a freeway in the Childhood Autism Risks from Genetics and the Environment (CHARGE) study.[7] The near-source traffic-related air pollutant mixture has a large spatial variation, returning to near-background daytime levels beyond this distance.[8,9] Herein, we report associations of autism with estimates of exposure to the mixture of traffic-related air pollution and with regional measures of nitrogen dioxide, particulate matter less than 2.5 μm in aerodynamic diameter ($PM_{2.5}$), and particulate matter less than 10 μm in aerodynamic diameter (PM_{10}) in the CHARGE sample.

METHODS

The CHARGE study is a population-based case-control study of preschool children. The study design is described in detail elsewhere.[10] In brief, the participants in the CHARGE study were between the ages of 24 and 60 months at the time of recruitment, lived with at least one English- or Spanish-speaking biologic parent, were born in California, and lived in one of the study catchment areas. Recruitment was facilitated by the California Department of Developmental Services, the regional centers with which they contract to coordinate services for persons with developmental disabilities, and referrals from the MIND (Medical Investigation of Neurodevelopmental Disorders) Institute clinic at the University of California, Davis, and from other research studies. Population-based control children were recruited from the sampling frame of birth files from the state of California and were frequency matched by sex, age, and broad geographic area to the children with autism.

Each participating family was evaluated. Children with a previous diagnosis of autism were evaluated using the Autism Diagnostic Observation Schedules, and parents were administered the Autism Diagnostic Interview–Revised.[11,12] Children who received a diagnosis of developmental delay and control children from the general population were given the Social Communication Questionnaire to screen for the presence of autistic features.[13] If the Social Communication Questionnaire score was 15 or greater, the child was then evaluated using the Autism Diagnostic Observation Schedules, and the parent was administered the Autism Diagnostic Interview–Revised. In our study, autism cases were children with a diagnosis of full syndrome autism from both the Autism Diagnostic Observation Schedules and the Autism Diagnostic Interview–Revised. All children were also assessed using the Mullen Scales of Early Learning and the Vineland Adaptive Behavior Scales to collect information on motor skills, language, socialization, and daily living skills.[14,15] Controls were children from the general population who received a Social Communication Questionnaire score of less than 15 and who also showed no evidence of other types of delay (cognitive or adaptive).

Parents were interviewed to obtain, among other factors, demographic and medical information and residential histories. Race/ethnicity data were collected by self-report in categories defined by the US Census (**Table 1**). The residential data captured addresses and corresponding dates the mother and child lived at each location beginning 3 months before conception and extending to the most recent place of residence. Further details about the collection of clinical and exposure data have been previously reported.[10]

To obtain model-based estimates of exposure to traffic-related air pollution, we applied the CALINE4 line-source air-quality dispersion model.[16] The dispersion model was used to estimate average concentrations for the specific locations and time periods (trimesters of gestation and first year of life) for each participant. The principal model inputs are roadway geometry, link-based traffic volumes, period-specific meteorological conditions (wind speed and direction, atmospheric stability, and mixing heights), and vehicle emission rates. Detailed roadway geometry data and annual average daily traffic counts were obtained from Tele Atlas/Geographic Data Technology in 2005. These data represent an integration of state-, county-, and city-level traffic counts collected between 1995 and 2000. Because our period of interest was from 1997 to 2008, the counts were scaled to represent individual years based on estimated growth in county average vehicle-miles-traveled data.[17] Traffic counts were assigned to roadways based on location and street names. Traffic volumes on roadways without count data (mostly small roads) were estimated based on median volumes for similar class roads in small geographic regions. Meteorological data from 56 local monitoring stations were matched to the dates and locations of interest. Vehicle fleet average emission factors were based on the California Air Resource Board's EMFAC2007 (version 2.3) model. Annual average emission factors were calculated by year (1997-2008) for travel on freeways (65 mph), state highways (50 mph), arterials (35 mph), and collector roads (30 mph) (to convert to kilometers, multiply by 1.6). We used the CALINE4 model to estimate locally varying ambient concentrations of nitrogen oxides contributed by freeways, nonfreeways, and all roads located within 5 km of each child's home. Previously, we have used the CALINE4 model to estimate concentrations of other traffic-related pollutants, including elemental carbon and carbon monoxide, and found that they were almost perfectly correlated (around 0.99) with estimates for nitrogen oxides. Thus, our model-based concentrations should be viewed as an indicator of the traffic-related pollutant mixture rather than of any pollutant specifically.

A second approach was to use the regional air quality data for the exposure assignments for $PM_{2.5}$, PM_{10}, ozone, and nitrogen dioxide. These were derived from the US Environmental Protection Agency's Air Quality System data (http://www.epa.gov/ttn/airs/airsaqs) supplemented by University of Southern California Children's Health Study data for 1997 though 2009.[18] The Children's Health Study continuous PM data were used for a given monitoring station when no Federal Reference/Equivalent Method data for PM were available from the Air Quality System. The monthly air quality data from monitoring stations located within 50 km of each residence were made available for spatial interpolation of ambient concentrations. The spatial interpolations were based on inverse distance–squared weighting of data from up to 4 of the closest stations located within 50 km of each participant's residence; however, if 1 or more stations were located within 5 km of a residence, then only data from the stations within 5 km were used for the interpolation. Because special studies have shown large offshore-to-onshore pollutant gradients along the Southern California coast, the interpolations were performed with pseudostations (or theoretical locations used for estimating pollution gradients from extant data when geography did not permit observed data) located approximately 20 to 40 km offshore that had background concentrations based on long-term measurements (1994-2003) at clean coastal locations (ie, Lompoc, California).

Periods and locations relevant to the modeled traffic exposure were identified based on dates and addresses recorded on the child's birth certificate and from the residential history questionnaire. The birth certificate addresses corresponded to the mother's residence at the time of the child's birth, whereas the residential history captures both the mother's residences during pregnancy (required for estimation of prenatal exposure) and the child's residences after birth through the time of study enrollment. We determined the conception date for each child using gestational age from ultrasonographic measurements or the date of last menstrual period, as determined from prenatal records. We used these locations and dates to estimate exposure for the child's first year of life, for the entire pregnancy period, and for each trimester of pregnancy. When more than 1 address fell into a time interval, we created a weighted average to reflect the exposure level of the participant across the time of interest, taking into account changes in residence. Traffic-related air pollution was determined based on the required inputs reflecting change in each address over the study period. For the regional pollutant measures, we assigned $PM_{2.5}$, PM_{10}, and nitrogen dioxide measurements based on average concentrations for the time period of interest. For ozone, we calculated the averages for the period of interest based on the average range of ozone measurements from 1000 to 1800 hours (reflecting the high 8-hour daytime). Based on these methods, we were able to assign traffic-related air pollutant estimates and regional pollutant measures for 524 mother-child pairs.

Spearman correlations were calculated pairwise between traffic-related air pollutant estimates and regional pollution measures for pregnancy and the first year of life to assess the independence of these exposure metrics. We used logistic regression to examine the association between exposure to traffic-related air pollution and the risk of autism. Models of autism risk as a function of traffic-related air pollutant exposure levels from all road types were fitted separately for each time period. Categories of exposure were formed based on quartiles of the traffic-related air pollutant distribution for all pregnancy estimates because this provided the most comprehensive data for each child. Levels of regional pollutants were examined as continuous variables, and effect estimates were scaled to twice the standard deviation of the distribution for all pregnancy estimates. When levels of correlation permitted, we examined both traffic-related air pollutants and regional pollutants in a single model. Pertinent covariates were included in each model to adjust for potential confounding due to sociodemographic and lifestyle characteristics. We included children's sex and ethnicity, maximum education level of the parents, mother's age, and whether the mother smoked during her pregnancy, as described previously.[7] To examine whether our findings were affected by participants living in an urban or rural area, we included population density, which was obtained from Environmental Systems Research Institute Inc 2008 estimates of people per square meter using ArcGIS software version 9.2. We used the US Census Bureau cutoff of 2500 people per square meter to categorize population density into urban vs rural areas and included this variable as a covariate in our analysis of the effects of air pollution from the first year of life because these residences were the most recently recorded.

We also fitted logistic additive models to evaluate the relationship between autism and traffic-related air pollution. These models used the smoothing spline with 3 degrees of freedom for continuous traffic-related air pollution and used the same adjustment variables as in the linear logistic models already described. Statistical tests were conducted using an α level of .05, and 95% CIs were used to measure precision. All analyses were conducted using the R package version 2.9.2 (http://www.r-project.org). The institutional review boards of the University of Southern California and the University of California, Davis, approved the research.

RESULTS

The children in our study were predominantly male (84%), and most were non-Hispanic white (50%) or Hispanic (30%). No differences were found between cases and controls for any demographic, socioeconomic, or lifestyle variables that we examined (eTable, http://www.archgenpsychiatry.com). Details regarding the exposure distributions are presented in the eFigure, A and B. The Spearman correlations calculated for the first year of life and the pregnancy time periods are presented in Table 1. During pregnancy and during the first year of life, traffic-related air pollution was moderately correlated with $PM_{2.5}$ and PM_{10}, highly correlated with nitrogen dioxide, but inversely correlated with ozone. Among the regional pollutant measures, $PM_{2.5}$ and PM_{10} were nearly perfectly correlated, and both were highly correlated with nitrogen dioxide. Correlations with ozone were low and often negative, demonstrating an inverse relationship. We also examined correlations of each pollut-

Table 2. Risk of Autism for 524 Children, by Quartile[a] of Modeled Traffic-Related Air Pollution Exposure From All Road Types

	Odds Ratio (95% CI)		
Time Period	**4th Quartile**	**3rd Quartile**	**2nd Quartile**
First year of life			
Crude	2.97 (1.71-5.27)	1.00 (0.63-1.60)	0.88 (0.55-1.42)
Adjusted[b]	3.10 (1.76-5.57)	1.00 (0.62-1.62)	0.91 (0.56-1.47)
All pregnancy			
Crude	1.99 (1.22-3.28)	1.10 (0.67-1.78)	1.20 (0.74-1.95)
Adjusted[b]	1.98 (1.20-3.31)	1.09 (0.67-1.79)	1.26 (0.77-2.06)
First trimester			
Crude	1.91 (1.67-3.14)	1.28 (0.80-2.06)	1.28 (0.77-2.14)
Adjusted[b]	1.85 (1.11-3.08)	1.28 (0.79-2.08)	1.28 (0.77-2.15)
Second trimester			
Crude	1.69 (1.04-2.78)	1.15 (0.71-1.87)	0.89 (0.54-1.47)
Adjusted[b]	1.65 (1.00-2.74)	1.13 (0.69-1.84)	0.90 (0.54-1.49)
Third trimester			
Crude	2.04 (1.25-3.38)	0.92 (0.57-1.48)	1.12 (0.68-1.84)
Adjusted[b]	2.10 (1.27-3.51)	0.91 (0.56-1.46)	1.17 (0.71-1.93)

[a] Quartile cut points correspond to traffic-related air pollution exposure levels of 31.8 ppb or greater (fourth quartile), 16.9 to 31.8 ppb (third quartile), and 9.7 to 16.9 ppb (second quartile), compared with 9.7 ppb or less (first quartile [reference group]).

[b] Model adjusted for male sex of child, child's ethnicity (Hispanic vs white; black/Asian/other vs white), maximum education of parents (parent with highest of 4 levels: college degree or higher vs some high school, high school degree, or some college education), maternal age (>35 years vs ≤35 years), and prenatal smoking (mother's self-report of ever vs never smoked while pregnant).

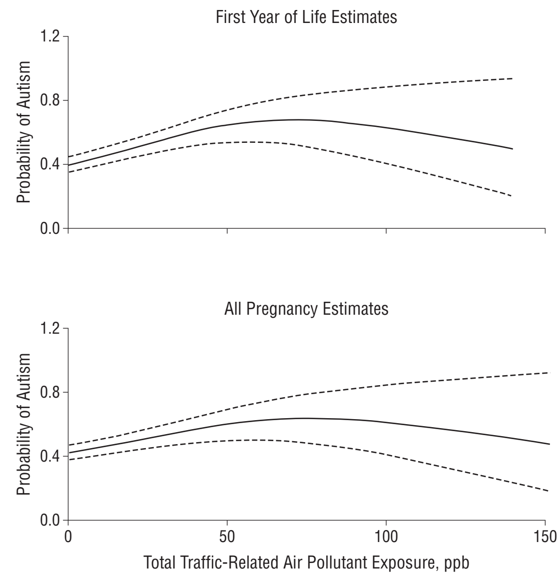


Figure. Probability of autism by increasing level of children's exposure to traffic-related air pollution during the first year of life and during gestation. The dashed lines indicate the 95% CI.

ant across time periods, and high levels of correlation were identified.

EXPOSURE TO TRAFFIC-RELATED AIR POLLUTION

An increased risk of autism was associated with exposure to traffic-related air pollution during a child's first year of life. Children residing in homes with the highest levels of modeled traffic-related air pollution were 3 times as likely to have autism compared with children residing in homes with the lowest levels of exposure (**Table 2**). Exposure in the middle quartile groups (second and third quartiles) was not associated with an increased risk of autism. In our analysis, which included population density, this association with the highest quartile of exposure was still evident (adjusted odds ratio [AOR], 3.48 [95% CI, 1.81-6.83]), and living in an urban area, compared with living in a rural area, was not associated with autism (AOR, 0.86 [95% CI, 0.56-1.31]). When we examined traffic-related air pollutant exposures during pregnancy, the highest quartile was also associated with autism risk (AOR, 1.98 [95% CI, 1.20-3.31]) compared with the lowest quartile. We further divided the pregnancy into 3 trimesters and modeled traffic-related air pollution based on these intervals. During all 3 trimesters of pregnancy, we found associations with the highest quartile of exposure (≥31.8 ppb), compared with the lowest quartile (≤9.7 ppb), and autism (Table 2). Inclusion of demographic and socioeconomic variables in the models did not greatly alter these associations (Table 2).

Because our quartile-based categories indicated that there is a threshold upon which traffic-related air pollutant exposure is detrimental, we also examined the relationship between traffic-related air pollutant exposure and autism using smoothed models for the first year of life and all of pregnancy. An increasing probability of autism was seen with increasing traffic-related air pollutant estimates, with the odds reaching a plateau when these estimates were above 25 to 30 ppb (**Figure**).

REGIONAL AIR POLLUTANT EXPOSURE

The higher levels of exposure to $PM_{2.5}$, PM_{10}, and nitrogen dioxide based on the Environmental Protection Agency's regional air quality monitoring program were associated with an increased risk of autism (**Table 3**). Specifically, for an 8.7-unit increase (micrograms per cubic meter) in $PM_{2.5}$ (corresponding to twice the standard deviation of the $PM_{2.5}$ distribution) exposure during the first year of life, children were 2.12 times more likely to have autism. Increases were also present for pregnancy and trimester-specific estimates of $PM_{2.5}$, with the smallest effects present in the first trimester. For PM_{10}, a 14.6-unit increase (micrograms per cubic meter) during the first year was associated with twice the risk of autism (Table 3). Associations were present for pregnancy and for each trimester, with the first trimester having the smallest magnitude. We did not find associations between levels of regional ozone and autism. Regional nitrogen dioxide exposure during the first year was associated with a 2-fold risk of autism. Similar effects were identified for nitrogen dioxide exposure during pregnancy. Although exposure during each of the 3 trimesters was associated with autism, the effects of the first trimester were the smallest. For all regional pollutant measures, adjustment for demographic and socioeconomic

Table 3. Risk of Autism for 524 Children Based on Continuous Regional Pollutant Exposure[a]

	Odds Ratio (95% CI)			
Time Period	$PM_{2.5}$	PM_{10}	Ozone	Nitrogen Dioxide
First year				
Crude	2.14 (1.48-3.09)	2.14 (1.47-3.10)	1.15 (0.72-1.84)	2.06 (1.39-3.06)
Adjusted[b]	2.12 (1.45-3.10)	2.14 (1.46-3.12)	1.15 (0.72-1.86)	2.06 (1.37-3.09)
All pregnancy				
Crude	2.11 (1.46-3.03)	2.17 (1.50-3.13)	1.08 (0.76-1.52)	1.82 (1.26-2.64)
Adjusted[b]	2.08 (1.93-2.25)	2.17 (1.49-3.16)	1.09 (0.76-1.55)	1.81 (1.23-2.65)
First trimester				
Crude	1.24 (0.99-1.56)	1.47 (1.10-1.98)	1.07 (0.86-1.33)	1.47 (1.07-2.01)
Adjusted[b]	1.22 (0.96-1.53)	1.44 (1.07-1.96)	1.08 (0.86-1.35)	1.44 (1.05-1.20)
Second trimester				
Crude	1.50 (1.16-1.93)	1.82 (1.35-2.45)	1.03 (0.84-1.27)	1.62 (1.17-2.25)
Adjusted[b]	1.48 (1.40-1.57)	1.83 (1.35-2.47)	1.04 (0.84-1.29)	1.61 (1.15-2.25)
Third trimester				
Crude	1.39 (1.11-1.75)	1.61 (1.21-2.13)	1.03 (0.84-1.27)	1.65 (1.19-2.27)
Adjusted[b]	1.40 (1.11-1.77)	1.61 (1.20-2.14)	1.03 (0.83-1.26)	1.64 (1.18-2.29)

Abbreviations: $PM_{2.5}$, particulate matter less than 2.5 μm in aerodynamic diameter; PM_{10}, particulate matter less than 10 μm in aerodynamic diameter.
[a] Regional pollution effects reflect risk of autism based on 2 SDs from the mean value, specifically per increase of 8.7 μg/m^3 of $PM_{2.5}$, 14.6 μg/m^3 of PM_{10}, 14.1 ppb of nitrogen dioxide, and 16.1 ppb of ozone.
[b] Models adjusted for male sex of child, child's ethnicity (Hispanic vs white; black/Asian/other vs white), maximum education of parents (parent with highest of 4 levels: college degree or higher vs some high school, high school degree, or some college education), maternal age (>35 years vs ≤35 years), and prenatal smoking (self-report of ever vs never smoked while pregnant).

variables did not alter the associations. As with traffic-related air pollution, when we included population density in the models that included exposure during the first year of life, the associations with $PM_{2.5}$, PM_{10}, and nitrogen dioxide did not change, nor did they change when living in an urban area vs a rural area was included (data not shown).

TRAFFIC-RELATED AIR POLLUTION, $PM_{2.5}$, AND PM_{10}

Because pairwise correlations between traffic-related air pollution and $PM_{2.5}$ and between traffic-related air pollution and PM_{10} were moderate, we included both in models to examine whether local pollution estimates (traffic-related air pollution) and regional pollution measures ($PM_{2.5}$ and PM_{10}) were independently associated with autism. In these analyses, we included the same set of covariates already described in the single pollutant analysis. When examined in the same model, the top quartile of traffic-related air pollutant exposure (AOR, 2.37 [95% CI, 1.28-4.45]) and the exposure to $PM_{2.5}$ (AOR, 1.58 [95% CI, 1.03-2.42]) during the first year of life remained associated with autism. Examining both traffic-related air pollution and PM_{10}, we found that the top quartile of traffic-related air pollutant exposure (AOR, 2.36 [95% CI, 1.28-4.43]) and the exposure to PM_{10} (AOR, 1.61 [95% CI, 1.06-2.47]) remained associated with autism. For the all pregnancy time interval, we found that the top quartile of traffic-related air pollutant exposure (AOR, 2.42 [95% CI, 1.32-4.50]) and the exposure to $PM_{2.5}$ (AOR, 1.60 [95% CI, 1.07-2.40]) were associated with autism when examined in the same model. Similarly, both the top quartile of traffic-related air pollutant exposure (AOR, 2.33 [95% CI, 1.27-4.36]) and the exposure to PM_{10} (AOR, 1.68 [95% CI, 1.11-2.53]) remained associated with autism when examined jointly.

COMMENT

Our study found that local estimates of traffic-related air pollution and regional measures of $PM_{2.5}$, PM_{10}, and nitrogen dioxide at residences were higher in children with autism. The magnitude of these associations appear to be most pronounced during late gestation and early life, although it was not possible to adequately distinguish a period critical to exposure. Children with autism were 3 times as likely to have been exposed during the first year of life to higher modeled traffic-related air pollution compared with control children with typical development. Similarly, exposure to traffic-related air pollution during pregnancy was also associated with autism. Examination of traffic-related air pollution using an additive logistic model demonstrated a potential threshold near 25 to 30 ppb beyond which the probability of autism did not increase. Exposure to high levels of regional $PM_{2.5}$, PM_{10}, and nitrogen dioxide were also associated with autism. When we examined $PM_{2.5}$ or PM_{10} exposure jointly with traffic-related air pollutant exposure, both regional and local pollutants remained associated with autism, although the magnitude of the effects decreased.

We previously reported an association between living near a freeway (based on the location of the birth and third trimester address) and autism.[7] That result relied on simple distance metrics as a proxy for exposure to traffic-related air pollution. The present study builds on that result, demonstrating associations with both regional particulate and nitrogen dioxide exposure and to dispersion-modeled exposure to the near-roadway traffic mixture accounting for traffic volume, fleet emission factors, and wind speed and direction, in addition to traffic proximity. The results provide more convincing evidence that exposure to local air pollution from traffic may increase the risk of autism. Demographic or socioeconomic factors did not explain these associations.

Toxicological and genetic research suggests possible biologically plausible pathways to explain these results. Concentrations of many air pollutants, including diesel exhaust particles and other PM constituents, are increased near freeways and other major roads, and diesel exhaust particles and polycyclic aromatic hydrocarbons (commonly present in diesel exhaust particles) have been shown to affect brain function and activity in toxicological studies.[19-23] Polycyclic aromatic hydrocarbons have been shown to reduce expression of the *MET* receptor tyrosine kinase gene, which is important in early life neurodevelopment and is markedly reduced in autistic brains.[24,25] Other research indicates that traffic-related air pollution induces inflammation and oxidative stress after both short- and long-term exposure, processes that mediate the effects of air pollution on respiratory and cardiovascular disease and other neurological outcomes.[26-29] Data examining biomarkers suggest that oxidative stress and inflammation may also be involved in the pathogenesis of autism.[30-33]

Emerging evidence suggests that systemic inflammation may also result in damage to endothelial cells in the brain and may compromise the blood-brain barrier.[29] Systemic inflammatory mediators may cross the blood-brain barrier, activating brain microglia, and peripheral monocytes may migrate into the pool of microglia.[34-36] In addition, ultrafine particles ($PM_{0.1}$) may penetrate cellular membranes.[37,38] These particles translocate indirectly through the lungs and from the systemic circulation or directly via the nasal mucosa and the olfactory bulb into the brain.[39,40] Toxicity may be mediated by the physical properties of PM or by the diverse mixture of organic compounds, including polycyclic aromatic hydrocarbons, and oxidant metals adsorbed to the surface.[29] Neurodevelopmental effects of polycyclic aromatic hydrocarbons may be mediated by aryl hydrocarbon hydroxylase induction in the placenta, decreased exchange of oxygen secondary to disruption of placental growth factor receptors, endocrine disruption, activation of apoptotic pathways, inhibition of the brain antioxidant-scavenging system resulting in oxidative stress, or epigenetic effects.[21]

Our study draws on a rich record of residential locations of children with typical development and children with autism across California, allowing us to assign modeled pollutant exposures for developmentally relevant time points. However, our results could also be affected by unmeasured confounding factors associated with both autism and exposure to traffic-related air pollution. Although we did not find that including demographic or socioeconomic variables altered our estimates of effect, confounding by other factors could still occur. These might include lifestyle, nutritional, or other residential exposures, if they were associated with traffic-related air pollution or PM. We have also not explored indoor sources of pollution, such as indoor nitrogen oxide or secondhand tobacco smoke, although prenatal smoking was examined and did not influence the associations of ambient pollution with autism. In addition, confounding could have occurred if proximity to diagnosing physicians or treatment centers was also associated with exposure. We included population density as an adjustment in an analysis using estimates from the first year of life to examine the sensitivity of our results to urban or rural locations, for which population density is a surrogate. We did not find that living in a more densely populated area altered the association between risk of autism and exposure to traffic-related air pollution or regional pollutants. Despite our attempts to use residential history to examine specific time windows of vulnerability, to incorporate meteorology into our traffic-related air pollutant models, and to include pollutants with seasonal variation, we are currently unable to disentangle the trimester-specific effects during the first year of life because of the high level of correlation across these time periods.

Exposures to traffic-related air pollution, PM, and nitrogen dioxide were associated with an increased risk of autism. These effects were observed using measures of air pollution with variation on both local and regional levels, suggesting the need for further study to understand both individual pollutant contributions and the effects of pollutant mixtures on disease. Research on the effects of exposure to pollutants and their interaction with susceptibility factors may lead to the identification of the biologic pathways that are activated in autism and to improved prevention and therapeutic strategies. Although additional research to replicate these findings is needed, the public health implications of these findings are large because air pollution exposure is common and may have lasting neurological effects.

Submitted for Publication: December 9, 2011; final revision received March 30, 2012; accepted April 3, 2012.
Published Online: November 26, 2012. doi:10.1001/jamapsychiatry.2013.266
Author Affiliations: Departments of Preventive Medicine (Drs Volk and McConnell) and Pediatrics (Dr Volk), Keck School of Medicine (Drs Volk and McConnell), Zilkha Neurogenetic Institute (Dr Volk), and Children's Hospital Los Angeles (Dr Volk), University of Southern California; Department of Public Health Sciences, University of California, Davis (Dr Hertz-Picciotto); and Sonoma Technology, Inc, Petaluma (Messrs Lurmann and Penfold), California.
Correspondence: Heather E. Volk, PhD, MPH, Departments of Preventive Medicine and Pediatrics, University of Southern California, 2001 N Soto St, MC 9237, Los Angeles, CA 90089 (hvolk@usc.edu).
Author Contributions: Dr Volk had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Conflict of Interest Disclosures: Dr Volk received support from Autism Speaks to present research findings at the International Society for Environmental Epidemiology Meeting in 2012. Messrs Lurmann and Penfold are employed by Sonoma Technology, Inc. Dr McConnell has received support from an air quality violations settlement agreement between the South Coast Air Quality Management District (a California state regulatory agency) and British Petroleum.
Funding/Support: This work was supported by National Institute of Environmental Health Sciences grants

ES019002, ES013578, ES007048, ES11269, ES015359, EPA Star-R-823392, and EPA Star-R-833292 and by the MIND Institute's matching funds and pilot grant program.
Role of the Sponsor: The sponsors did not participate in the design and conduct of the study; in the collection, analysis, and interpretation of the data; or in the preparation, review, or approval of the manuscript.
Previous Presentations: Presented in part at the International Meeting for Autism Research; May 14, 2011; San Diego, California; and the Meeting of the International Society for Environmental Epidemiology; September 16, 2011; Barcelona, Spain.
Online-Only Material: The eTable and eFigure are available at http://www.archgenpsychiatry.com.

REFERENCES

1. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders*. 4th ed. Washington, DC: American Psychiatric Association; 2000.
2. Autism and Developmental Disabilities Monitoring Network Surveillance Year 2006 Principal Investigators; Centers for Disease Control and Prevention (CDC). Prevalence of autism spectrum disorders—Autism and Developmental Disabilities Monitoring Network, United States, 2006. *MMWR Surveill Summ*. 2009;58(10):1-20.
3. Windham GC, Zhang L, Gunier R, Croen LA, Grether JK. Autism spectrum disorders in relation to distribution of hazardous air pollutants in the San Francisco Bay Area. *Environ Health Perspect*. 2006;114(9):1438-1444.
4. Kalkbrenner AE, Daniels JL, Chen JC, Poole C, Emch M, Morrissey J. Perinatal exposure to hazardous air pollutants and autism spectrum disorders at age 8. *Epidemiology*. 2010;21(5):631-641.
5. Currie J, Neidell M, Schmieder JF. Air pollution and infant health: lessons from New Jersey. *J Health Econ*. 2009;28(3):688-703.
6. Hansen CA, Barnett AG, Pritchard G. The effect of ambient air pollution during early pregnancy on fetal ultrasonic measurements during mid-pregnancy. *Environ Health Perspect*. 2008;116(3):362-369.
7. Volk HE, Hertz-Picciotto I, Delwiche L, Lurmann F, McConnell R. Residential proximity to freeways and autism in the CHARGE study. *Environ Health Perspect*. 2011;119(6):873-877.
8. Zhu YF, Hinds WC, Kim S, Sioutas C. Concentration and size distribution of ultrafine particles near a major highway. *J Air Waste Manag Assoc*. 2002;52(9):1032-1042.
9. Zhu Y, Hinds WC, Kim S, Shen S, Sioutas C. Study of ultrafine particles near a major highway with heavy-duty diesel traffic. *Atmos Environ*. 2002;36(27):4323-4335. doi:10.1016/S1352-2310(02)00354-0.
10. Hertz-Picciotto I, Croen LA, Hansen R, Jones CR, van de Water J, Pessah IN. The CHARGE study: an epidemiologic investigation of genetic and environmental factors contributing to autism. *Environ Health Perspect*. 2006;114(7):1119-1125.
11. Le Couteur A, Lord C, Rutter M. *Autism Diagnostic Interview-Revised (ADI-R).* Los Angeles, CA: Western Psychological Services; 2003.
12. Lord C, Rutter M, DiLavore P, Risi S. *Autism Diagnostic Observation Schedule Manual.* Los Angeles, CA: Western Psychological Services; 2003.
13. Rutter M, Bailey A, Lord C. *A Social Communication Questionnaire (SCQ).* Los Angeles, CA: Western Psychological Services; 2003.
14. Sparrow S, Cicchettim D, Balla D. *Vineland Adaptive Behavior Scales Interview Edition Expanded Form Manual.* Circle Pines, MN: American Guidance Services Inc; 1984.
15. Mullen E. *Mullen Scales of Early Learning.* Circle Pines, MN: American Guidance Services Inc; 1995.
16. Bensen PE. A review of the development and application of the CA-LINE3 and 4 models. *Atmos Environ Part B: Urban Atmosphere*. 1992;26(3):379-390. doi:10.1016/0957-1272(92)90013-I.
17. California Department of Transportation. California motor vehicle stock, travel and fuel forecast. http://www.dot.ca.gov/hq/tsip/smb/documents/mvstaff/mvstaff05.pdf. Published December 30, 2005. Accessed September 18, 2012.
18. Alcorn SH, Lurmann FW. *Southern California Children's Health Study exposure database.* Petaluma, CA: Sonoma Technology, Inc; 2003. Technology Report STI-95230-2453-FR3.
19. Ntziachristos L, Ning Z, Geller MD, Sioutas C. Particle concentration and characteristics near a major freeway with heavy-duty diesel traffic. *Environ Sci Technol*. 2007;41(7):2223-2230.
20. Perera FP, Rauh V, Whyatt RM, Tsai WY, Tang D, Diaz D, Hoepner L, Barr D, Tu YH, Camann D, Kinney P. Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first 3 years of life among inner-city children. *Environ Health Perspect*. 2006;114(8):1287-1292.
21. Perera FP, Li Z, Whyatt R, Hoepner L, Wang S, Camann D, Rauh V. Prenatal airborne polycyclic aromatic hydrocarbon exposure and child IQ at age 5 years. *Pediatrics*. 2009;124(2):e195-e202.
22. Hougaard KS, Jensen KA, Nordly P, Taxvig C, Vogel U, Saber AT, Wallin H. Effects of prenatal exposure to diesel exhaust particles on postnatal development, behavior, genotoxicity and inflammation in mice. *Part Fibre Toxicol*. 2008;5:3.
23. Brown LA, Khousbouei H, Goodwin JS, Irvin-Wilson CV, Ramesh A, Sheng L, McCallister MM, Jiang GC, Aschner M, Hood DB. Down-regulation of early ionotrophic glutamate receptor subunit developmental expression as a mechanism for observed plasticity deficits following gestational exposure to benzo(a)pyrene. *Neurotoxicology*. 2007;28(5):965-978.
24. Levitt P, Campbell DB. The genetic and neurobiologic compass points toward common signaling dysfunctions in autism spectrum disorders. *J Clin Invest*. 2009;119(4):747-754.
25. Campbell DB, D'Oronzio R, Garbett K, Ebert PJ, Mirnics K, Levitt P, Persico AM. Disruption of cerebral cortex MET signaling in autism spectrum disorder. *Ann Neurol*. 2007;62(3):243-250.
26. Castro-Giner F, Künzli N, Jacquemin B, Forsberg B, de Cid R, Sunyer J, Jarvis D, Briggs D, Vienneau D, Norback D, González JR, Guerra S, Janson C, Antó JM, Wjst M, Heinrich J, Estivill X, Kogevinas M. Traffic-related air pollution, oxidative stress genes, and asthma (ECHRS). *Environ Health Perspect*. 2009;117(12):1919-1924.
27. Gilliland FD, Li YF, Saxon A, Diaz-Sanchez D. Effect of glutathione-S-transferase M1 and P1 genotypes on xenobiotic enhancement of allergic responses: randomised, placebo-controlled crossover study. *Lancet*. 2004;363(9403):119-125.
28. Künzli N, Jerrett M, Garcia-Esteban R, Basagaña X, Beckermann B, Gilliland F, Medina M, Peters J, Hodis HN, Mack WJ. Ambient air pollution and the progression of atherosclerosis in adults. *PLoS One*. 2010;5(2):e9096.
29. Block ML, Calderón-Garcidueñas L. Air pollution: mechanisms of neuroinflammation and CNS disease. *Trends Neurosci*. 2009;32(9):506-516.
30. Enstrom A, Krakowiak P, Onore C, Pessah IN, Hertz-Picciotto I, Hansen RL, Van de Water JA, Ashwood P. Increased IgG4 levels in children with autism disorder. *Brain Behav Immun*. 2009;23(3):389-395.
31. James SJ, Rose S, Melnyk S, Jernigan S, Blossom S, Pavliv O, Gaylor DW. Cellular and mitochondrial glutathione redox imbalance in lymphoblastoid cells derived from children with autism. *FASEB J*. 2009;23(8):2374-2383.
32. Li X, Chauhan A, Sheikh AM, Patil S, Chauhan V, Li XM, Ji L, Brown T, Malik M. Elevated immune response in the brain of autistic patients. *J Neuroimmunol*. 2009;207(1-2):111-116.
33. Ashwood P, Enstrom A, Krakowiak P, Hertz-Picciotto I, Hansen RL, Croen LA, Ozonoff S, Pessah IN, Van de Water J. Decreased transforming growth factor beta1 in autism: a potential link between immune dysregulation and impairment in clinical behavioral outcomes. *J Neuroimmunol*. 2008;204(1-2):149-153.
34. Nguyen MD, Julien JP, Rivest S. Innate immunity: the missing link in neuroprotection and neurodegeneration? *Nat Rev Neurosci*. 2002;3(3):216-227.
35. Banks WA, Farr SA, Morley JE. Entry of blood-borne cytokines into the central nervous system: effects on cognitive processes. *Neuroimmunomodulation*. 2002-2003;10(6):319-327.
36. D'Mello C, Le T, Swain MG. Cerebral microglia recruit monocytes into the brain in response to tumor necrosis factoralpha signaling during peripheral organ inflammation. *J Neurosci*. 2009;29(7):2089-2102.
37. Geiser M, Rothen-Rutishauser B, Kapp N, Schürch S, Kreyling W, Schulz H, Semmler M, Im Hof V, Heyder J, Gehr P. Ultrafine particles cross cellular membranes by nonphagocytic mechanisms in lungs and in cultured cells. *Environ Health Perspect*. 2005;113(11):1555-1560.
38. Rothen-Rutishauser B, Mueller L, Blank F, Brandenberger C, Muehlfeld C, Gehr P. A newly developed in vitro model of the human epithelial airway barrier to study the toxic potential of nanoparticles. *ALTEX*. 2008;25(3):191-196.
39. Campbell A, Araujo JA, Li H, Sioutas C, Kleinman M. Particulate matter induced enhancement of inflammatory markers in the brains of apolipoprotein E knock-out mice. *J Nanosci Nanotechnol*. 2009;9(8):5099-5104.
40. Oberdörster G, Elder A, Rinderknecht A. Nanoparticles and the brain: cause for concern? *J Nanosci Nanotechnol*. 2009;9(8):4996-5007.

Czepiga, Page (EEA)

From:	Wig Zamore <wigzamore@gmail.com>
Sent:	Tuesday, April 25, 2017 4:58 PM
To:	Czepiga, Page (EEA)
Cc:	bill deignan; Fred Salvucci; Andrea Adams; William Legault; david carlon
Subject:	Re: Logan Parking ENF Comment15665
Attachments:	Patton 2014 AE Spatial and temporal differences in traffic related air pollution in three urban neighborhoods near an interstate highway.pdf; Lane 2016 EI Association of modeled long term personal exposure to UFP with inflammatory and coagulation biomarkers.pdf; Hudda 2016 EST Aviation emissions impact ambient UFP concentrations in the greater Bostona rea.pdf

Finally, here are three of fourteen papers in the National Library of Medicine dealing with near source transportation impacts in Boston, on which I am co-author. Two of the papers (Patton and Lane) are from the NIH and EPA funded CAFEH project, which is the most detailed research in the world on transportation ultrafine particle (UFP) exposures and cardiovascular inflammatory biomarkers. It is a small population study, done at 20 meter grid for every hour of the year for every study participant. We showed a statistically ssignificant relationship between our Causcasian study population and three cardiovascular biomarkers, including C Reactive Protein and Interluekin 6, the most used markers of cardiovascular risk in large population studies. The third paper (Hudda) details Logan Airport activity impact on UFP concentrations in Chelsea, most notably, as well as Roxbury and Dorchester, when winds are from Logan and toward those neighborhoods. Environmental Science & Technology is generally considered to be one of the best environmental science journals in the world. I presented the Hudda paper at last year's International Society of Environmental Epidemiology annual meeting, in Rome. Best Regards, Wig

On Tue, Apr 25, 2017 at 4:43 PM, Wig Zamore <wigzamore@gmail.com> wrote:
The BC Guide - Wig

On Tue, Apr 25, 2017 at 4:42 PM, Wig Zamore <wigzamore@gmail.com> wrote:
I have attached peer reviewed enviromental health science in support of my Logan Parking ENF comment. And a guide to using emissions factors and approved regulatory software to calculate climate impacts of Black Carbon. - Best Regards, Wig Zamore

On Tue, Apr 25, 2017 at 4:25 PM, Wig Zamore <wigzamore@gmail.com> wrote:
Please accept the brief Logan Parking ENF comment attached - Thanks very much, Wig Zamore

Environmental Science & Technology

Article

pubs.acs.org/est

Aviation Emissions Impact Ambient Ultrafine Particle Concentrations in the Greater Boston Area

N. Hudda,[†] M. C. Simon,[†] W. Zamore,[‡] D. Brugge,[§] and J. L. Durant*,[†]

[†]Department of Civil and Environmental Engineering, Tufts University, Medford, Massachusetts 02155, United States

[‡]Somerville Transportation Equity Partnership, Somerville, Massachusetts 02145, United States

[§]Department of Public Health and Community Medicine, Tufts University, Boston, Massachusetts 02111, United States

S *Supporting Information*

ABSTRACT: Ultrafine particles are emitted at high rates by jet aircraft. To determine the possible impacts of aviation activities on ambient ultrafine particle number concentrations (PNCs), we analyzed PNCs measured from 3 months to 3.67 years at three sites within 7.3 km of Logan International Airport (Boston, MA). At sites 4.0 and 7.3 km from the airport, average PNCs were 2- and 1.33-fold higher, respectively, when winds were from the direction of the airport compared to other directions, indicating that aviation impacts on PNC extend many kilometers downwind of Logan airport. Furthermore, PNCs were positively correlated with flight activity after taking meteorology, time of day and week, and traffic volume into account. Also, when winds were from the direction of the airport, PNCs increased with increasing wind speed, suggesting that buoyant aircraft exhaust plumes were the likely source. Concentrations of other pollutants [CO, black carbon (BC), NO, NO_2, NO_x, SO_2, and fine particulate matter ($PM_{2.5}$)] decreased with increasing wind speed when winds were from the direction of the airport, indicating a different dominant source (likely roadway traffic emissions). Except for oxides of nitrogen, other pollutants were not correlated with flight activity. Our findings point to the need for PNC exposure assessment studies to take aircraft emissions into consideration, particularly in populated areas near airports.

INTRODUCTION

Exposure to ultrafine particles (UFPs; aerodynamic diameter of <100 nm) is associated with adverse cardiovascular effects, including systemic inflammation biomarkers and ischemic heart disease.[1−3] Although ambient UFPs can form in the atmosphere through processes such as photochemical formation and condensation of vapors,[1] they primarily derive from anthropogenic combustion sources, such as power generation and transportation activities. In urban areas, roadway traffic emissions are a dominant source of UFPs and have been the focus of exposure assessment and epidemiological studies.[1] Recently, airport-related emissions were shown to also be a significant UFP source;[4−6] however, their impacts are less well-studied compared to roadway traffic. Distinguishing the contribution of airport-related emissions from traffic emissions can better inform exposure assessment efforts.[7−9]

Concentrations of UFPs emitted by vehicular traffic are typically highest on or near roadways but decrease rapidly within 200−300 m.[10] In contrast, the impacts from airport-related emissions on UFP concentrations can extend tens of kilometers from airports, encompassing large populated areas.[4−6] For example, Keuken et al.[5] reported a 200% increase in UFPs [measured as particle number concentrations (PNCs), a proxy for UFPs] at a site 7 km downwind from Schiphol Airport (Amsterdam, Netherlands) and a 20% increase at a background site 40 km downwind. Using dispersion modeling, Keuken et al.[5] estimated that aviation activity increased annual PNC exposures by 5000−10 000 particles cm^{-3} at 45 000 addresses. Hudda et al.[4] reported a 100−900% increase in PNCs over local background that extended 18 km downwind from Los Angeles International Airport (LAX, CA); UFPs < 40 nm constituted 75−90% of the elevated PNCs.[6]

Such impacts are likely not unique to the airports in these studies.[4−6] At locations with highly variable winds that change direction swiftly, for example, Logan International Airport in Boston, MA, the busiest airport in New England, the resulting impacts may be intermittent and dispersed over many downwind sectors. Patton et al.[11,12] found that wind-direction sectors that included the airport as an upwind source were a significant explanatory variable for PNCs in communities located 4−8 km north-northwest (NNW)−south-southwest (SSW) of the airport in Boston. We were motivated to examine newly available PNC data sets, collected as part of two near-roadway health studies in Boston,[13,14] for evidence of airport-related emission impact on ambient PNCs.

We analyzed PNCs measured continuously at three stationary sites within 7.3 km of the airport. Our objectives were to (1) test the hypothesis that flight activity was associated with PNCs when winds positioned these sites downwind of the airport, (2) analyze

Received: April 13, 2016
Revised: July 8, 2016
Accepted: July 19, 2016
Published: August 4, 2016

DOI: 10.1021/acs.est.6b01815
Environ. Sci. Technol. 2016, 50, 8514−8521

the dependence of PNCs upon wind speed to identify if PNCs were higher at higher wind speeds, which would indicate that the impact was likely from aircraft exhaust plumes, and (3) analyze collocated measurements at one site for a suite of pollutants to compare impacts across pollutants.

■ MATERIALS AND METHODS

Logan International Airport and Monitoring Sites. The General Edward Lawrence Logan International Airport occupies 6.8 km^2 on the north shore of Boston Harbor, 1.6 km east of downtown Boston (Figure 1a). Daily, about 850 jet and 160 non-jet aircraft operate at the airport. It has six runways: 22R/4L and 22L/4R are parallel and aligned to true north 200°/20°, 27/9 is aligned to 257°/77°, 32/14 is aligned to 306°/126°, and 33R/15L and 33L/15R are parallel and aligned to 315°/135° (Figure 1a). Diurnal trends and flight statistics by runway and wind direction are shown in Figure S1 and Table S1 of the Supporting Information.

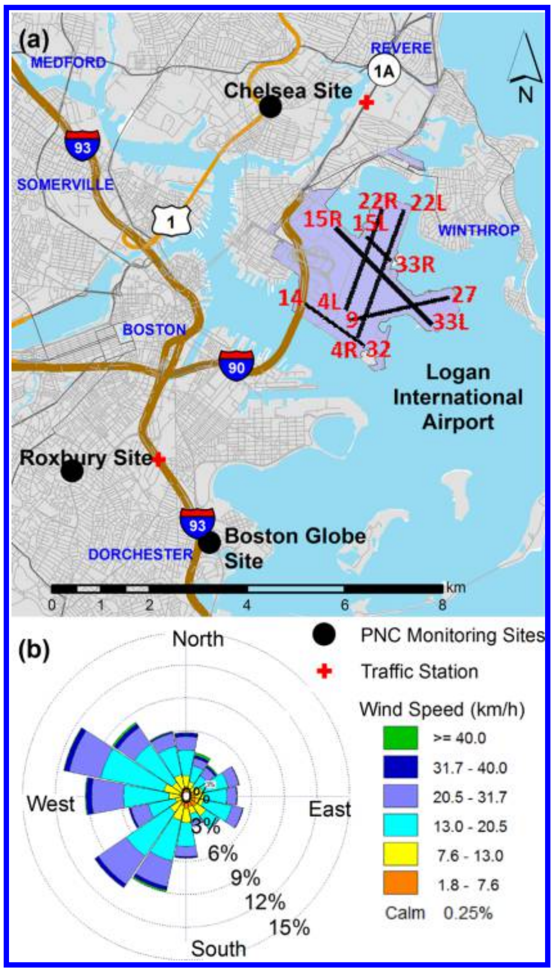


Figure 1. (a) Map shows runway configuration at Logan International Airport and locations of the three monitoring sites. Base layers for the map were obtained from mass.gov. (b) Wind rose based on 1 min data for 2014 reported by the National Weather Service automated surface station located at the airport.

During the study period (January 2012–August 2015) winds in the Boston area (Figure 1b) prevailed from west–north-northwest (W–NNW) (270–337.5°) in winter and south–west-southwest (S–WSW) (180–247.5°) in summer (30 and 26% frequency, respectively), consistent with the general pattern in the greater Boston area.[15] During prevailing winds, the majority of flights arrive and depart on runways 22L, 22R, 27/9, and 33L; thus, during these winds, the downwind advection of airport-related emissions occurs largely over the ocean and the communities located northeast of the airport (Figure 1a). During infrequent northeast (NE) (22.5–67.5°) and southeast (SE) (112.5–157.5°) winds (both occurred at 7% frequency), most flights use runways 22L/4R, 22R/4L, and 27/9, causing downwind advection of emissions over Boston and residential communities southwest–northwest (SW–NW) of the airport where our monitoring sites were located.

PNCs were monitored using condensation particle counters (CPCs, model 3783 at Chelsea and Roxbury and model 3775 at Boston Globe; TSI, Inc., Shoreview, MN) at three locations: (1) the roof of a three-story building in Chelsea, 4.0 km northwest of the airport, from January 2014–August 2015, (2) the roof of the two-story Boston Globe parking garage in Dorchester, 6.5 km southwest of the airport, from March–May 2011, and (3) the United States Environmental Protection Agency (U.S. EPA) Speciation Trends Network air quality monitoring site in Roxbury (EPA-STN, ID 25-025-0042), 7.3 km southwest of the airport, from January 2012–August 2015 (Figure 1a). We refer to these sites as Chelsea, Boston Globe and Roxbury, respectively. Further site and instrument details are provided in Tables S2 and S3 of the Supporting Information. Data quality assurance is also discussed in the Supporting Information. CPCs were calibrated annually at TSI, and side-by-side tests conducted in our laboratory indicate a good agreement ($r^2 = 0.97$; see Figure S2 of the Supporting Information).

Data Processing. Meteorological data, including wind direction and speed, reported as a 2 min running average at 1 min resolution, were obtained from the National Weather Service station at the airport[16] and averaged to obtain hourly values. Wind roses are shown in panels a–c of Figure S3 of the Supporting Information. Flight records for individual aircraft were obtained from the Massachusetts Port Authority (East Boston, MA) and counted to obtain hourly totals for landings, takeoffs, and the sum of the two, i.e., LTO. Data for aircraft idling and taxiing times, although likely correlated with LTO, were not available. We classified the hours 0600–2359 as high flight activity hours and 0000–0559 as low flight activity hours. During the study period, the average LTO (±1 standard deviation) during high and low activity hours were 46.2 ± 10.4 and 5.0 ± 5.3 h^{-1}, respectively (see Figure S1 of the Supporting Information).

Hourly average black carbon (BC), CO, NO, NO_2, NO_x, ozone, fine particulate matter ($PM_{2.5}$), and SO_2 concentrations and solar radiation monitored at the Roxbury site were also obtained.[17] These data were combined with hourly average PNCs. Hourly average baseline PNCs, the running fifth percentile over 5 min periods for the PNC time series, was also calculated to exclude short duration (<5 min) spikes, likely resulting from traffic near the monitoring sites, that could skew the averages. Further, hourly average PNCs and baseline PNCs were aggregated by 10° wide wind-direction sectors, and sector averages were calculated.

Statistical Analysis. To test the hypothesis that hourly total flight activity [i.e., LTO (number h^{-1})] was correlated with PNCs at Chelsea and Roxbury, we used non-parametric Spearman's correlation to avoid specifying a known, parametric relationship between PNCs and variables that might impact airport-related emission concentrations at distant sites. LTO, particle number, other pollutant concentrations (and their log-transformed values), and traffic and meteorological variables were generally non-normally distributed (Figure S4 of the Supporting Information). We present only bivariate correlations for the Boston Globe site as a result of limited monitoring (only 3 months versus 1.67 and 3.67 years at Chelsea and Roxbury). For Chelsea and Roxbury, we report the strength of partial correlation (r_s) and significance (p, considered significant if <0.01) between hourly LTO and PNCs (both hourly average and baseline hourly average), taking meteorological variation, temporal variation (hour of the day and weekday or weekend differentiation), and traffic (hourly traffic volume) into account. Hour of day was treated as a circular variable and resolved into sine and cosine components {sine and cosines of radians [$(2\pi/24) \times$ hour of day]}. Meteorological variables considered included temperature (°C), wind speed (km h^{-1}), and solar radiation [langley (Ly)/min, only available at Roxbury]. Wind direction was only used to classify data as impact or non-impact sector. The partial correlations were calculated between LTO and the residuals of PNCs after regression of impact-sector PNCs on the controlled variables (i.e., between LTO and the component of PNCs uncorrelated with controlled variables). This approach helps address the problem of collinearity between flight activity and vehicular traffic volume.

Because measurements for local street traffic were unavailable, we assumed that local traffic patterns were proportional to those measured at the closest traffic monitor on highways (Figure S5 of the Supporting Information).[18] For the Roxbury site, we used concurrent measurements from Interstate-93 (I-93) station 8494, located south of downtown Boston between the site and the airport. For the Chelsea site, the nearest traffic monitoring station was located on highway 1A (station 8087, located north of the airport and northeast of the site), but data were only available for 165 days of the 20 month monitoring period. A cubic spline fit based on hour of the day accounted for 80 and 90% of the variation in traffic volume on highway 1A on weekdays and weekends, respectively (Table S4 of the Supporting Information). Therefore, it was a reasonable proxy for temporal variation in local traffic volume. Additionally, at the Roxbury site, we also used collocated measurements of CO and NO_x as a proxy for traffic congestion in an upwind area. We observed coincident concentration spikes of these pollutants and PNCs when winds were from the direction of busy intersections in the vicinity of the site (southeast and west; panels a−c of Figure S10 of the Supporting Information). $PM_{2.5}$ and ozone were also used as controls to account for factors, such as frontal weather and photochemical formation, that impact PNCs at a regional scale.

■ RESULTS AND DISCUSSION

Wind Direction and PNC Patterns. At all three monitoring sites, baseline PNC roses and PNC plots for 10° wide sectors, shown in Figure 2 and Figure 3, indicated an emission source in the upwind direction that coincided with the azimuth angle between the sites and the airport. These plots were used to identify impact sectors, i.e., site-specific wind-direction sectors, that were likely impacted by airport-related emissions. Impact-sector widths varied from 20° to 45°. See Table S5 of the Supporting Information for impact-sector boundaries and summary of PNCs.

Impact-sector PNCs were nearly 2-fold higher during high flight activity hours compared to low activity hours. However, high and low flight activity hours are also high and low traffic activity hours, and thus, the difference is indicative of the reduction in general transportation activity. Nonetheless, this

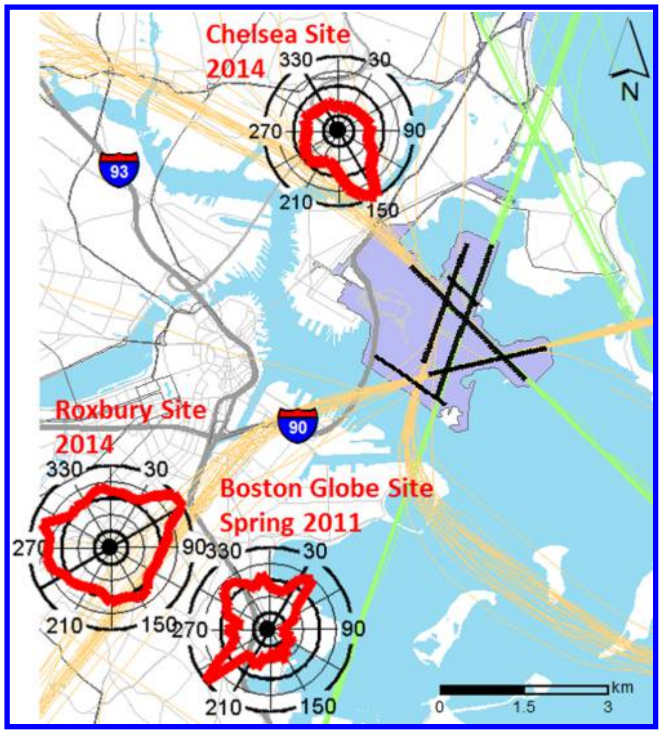


Figure 2. Hourly average baseline PNC roses (normalized to the maximum) for the three monitoring sites. Typical trajectories for frequently used runways for landings are shown in green, and takeoffs are shown in tan. Base layers for the map were obtained from mass.gov.

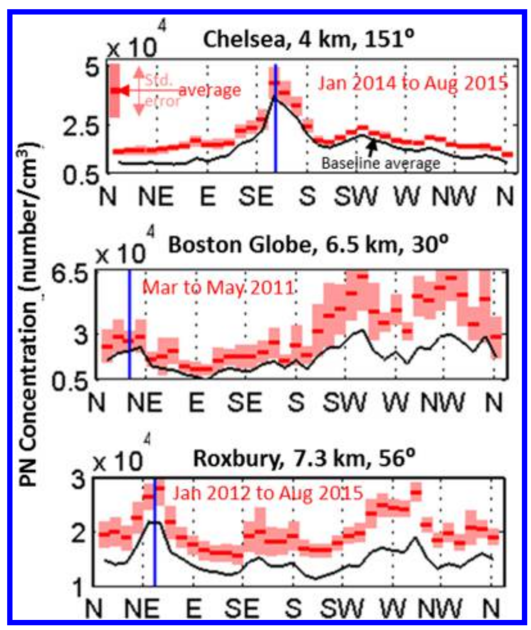


Figure 3. Hourly average PNC aggregated by 10° wide wind-direction sectors. Sector-average PNCs are plotted as dark red lines, and ±1 standard error is shaded red. Sector-average baseline PNCs are shown as a black line. The azimuth angle between the site and the airport is indicated by the vertical blue line.

difference was accentuated for impact-sector winds compared to other directions (2.1-fold at Chelsea and 1.9-fold at Roxbury compared to 1.4-fold at Chelsea and 1.7-fold at Roxbury for other wind directions; Figure S6 of the Supporting Information). Furthermore, during 0100−0359 h, when flight activity was minimal (average arrivals and departures in 2014 were 1.6 and

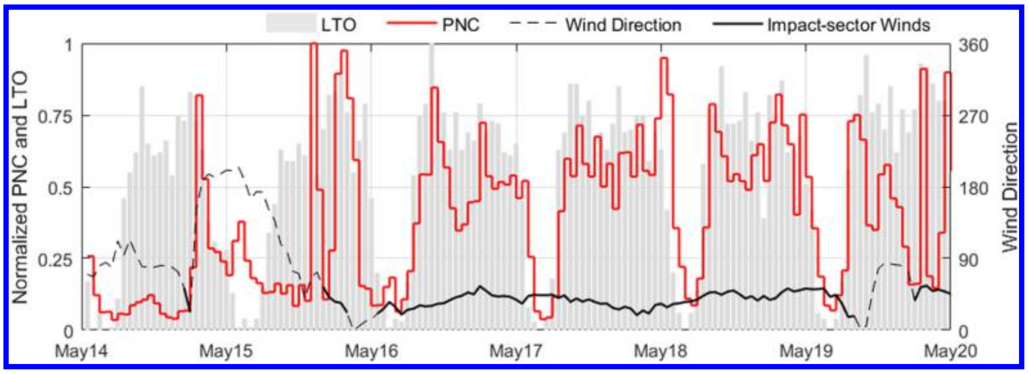


Figure 4. Time series for wind direction, LTO (flight operations/h), and hourly average PNCs at the Boston Globe site. Impact-sector (15−60°) winds are highlighted as a solid black line, and PNCs and LTO were normalized by the maximum during the week.

0.2 h^{-1}, respectively), PNC averages for impact-sector winds and all other wind directions were comparable. Atmospheric transformation of UFPs (physical and chemical) differ between nighttime and daytime hours, but these effects are expected to be independent of the wind direction.

Chelsea Monitoring Site. PNCs were elevated at the Chelsea site, 4.0 km downwind from the geographic center of the airport, during south-southeast (SSE) winds (impact sector = 135−175°) (Figure 2 and Figure 3). The highest of these elevated concentrations were associated with 145−155° winds, coinciding with a 151° azimuth angle between the site and the airport. The annual (2014) average impact-sector PNC was 2-fold higher than the average for all other wind directions [35 000 ± 75% (average ± relative standard deviation) compared to 18 000 ± 69% particles cm^{-3}]. PNCs were consistently elevated during impact-sector winds across years, seasons, and times of day, except for minimal flight activity hours (panels a−d of Figure S7 of the Supporting Information). The duration of impact-sector winds was mostly a few hours; only 10% of the data was from instances of 6 or more continuous hours of impact-sector winds. During the two longest periods of sustained impact-sector winds (18 h and 26 h), PNCs and LTO were strongly correlated ($r_s > 0.81$; $p < 0.01$; Figure S7e of the Supporting Information). The highest of the daily averages (>50 000 particles cm^{-3}) was observed on the days with the most hours of impact-sector winds (Figure S7f of the Supporting Information). Relatively high PNCs were also observed (2014 average was 22 000 ± 53% particles cm^{-3}) during southwesterly winds when highway 1 (2.6 × 10^4 vehicles/day) and local streets and intersections were upwind of the Chelsea site (Figure 1).

Boston Globe Monitoring Site. PNCs were elevated at the Boston Globe site during northeasterly winds (impact sector = 15−60°). The site was 6.5 km downwind of the airport along a 30° azimuth angle measured from the site to the airport (Figure 2 and Figure 3). The impact-sector average PNC was 25 000 ± 118% particles cm^{-3}. Although contributions from traffic emissions on Morrissey Boulevard (4 × 10^4 vehicles/day, about 100 m upwind of the site during impact-sector winds) cannot be ruled out, our results show that aircraft contributions can be distinguished at this site. The strongest correlations (Spearman's rank correlation) between PNCs and LTO across all 36 10° sectors were observed when wind was from the direction of the airport, i.e., 15−45° (panels b and c of Figure S8 of the Supporting Information). A stronger correlation was observed for sustained impact-sector winds compared to all hours, including short sporadic periods of impact-sector winds. Figure 4 and Figure S8d of the Supporting Information show a 3 day period (May 16−18, 2011) of sustained impact-sector winds when PNCs and LTO were strongly correlated ($r_s = 0.68$; $p < 0.01$). During this period, 97% of the flights landed on runway 4R (aircraft heading = 20°) and 84% departed from runway 9 (aircraft heading = 77°). For all hours of impact-sector winds in May 2011, r_s was 0.62 ($p < 0.01$; $n = 196$ h). In contrast, there was no correlation between PNCs and LTO for winds other than from the impact sector ($r_s = 0.08$; $p > 0.01$; $n = 414$ h). High PNCs during southwest to northwest winds (44 000 ± 88% particles cm^{-3}) are attributable to traffic on I-93 (2 × 10^5 vehicles/day) located 25 m west of the monitor.

Roxbury Monitoring Site. At the Roxbury site, 7.3 km downwind from the airport, elevated PNCs were observed during east-northeast (ENE) winds (impact sector = 45−65°) (Figure 2 and Figure 3). The highest concentrations were associated with the 50−60° winds, coinciding with a 56° azimuth angle measured between the site and the airport. The annual (2014) average impact-sector PNC was 1.33-fold higher than the average for all other directions (28 000 ± 54% compared to 21 000 ± 65% particles cm^{-3}). PNCs were consistently elevated during impact-sector winds across years, seasons, and times of day, except for minimal flight activity hours (panels a−d of Figures S9 of the Supporting Information). The duration of impact-sector winds was mostly one or a few hours; only 20% of the data was from instances of 6 or more continuous hours of impact-sector winds. During the two longest periods of sustained impact-sector winds (20 and 30 h), PNCs and LTO were strongly correlated ($r_s > 0.79$; $p < 0.01$; Figure S9e of the Supporting Information). Similar to the Chelsea site, daily PNC averages were higher on days with more hours of impact-sector winds (Figure S9f of the Supporting Information). However, unlike the Chelsea site, the highest of the daily averages at Roxbury site (>50 000 particles cm^{-3}) did not coincide with impact-sector winds but with northwest winds in winter (reflecting contributions from traffic-related emissions). The impact-sector average PNC was comparable to the average during westerly winds (Table S5 of the Supporting Information), which orient the site downwind of a bus depot (100 m) and highway 28 (0.75−1 km).

Correlation between PNCs and Flight Activity. PNCs were positively correlated with LTO during impact-sector winds, as indicated by hourly average PNCs plotted versus LTO (colored by ambient temperature) in Figure 5. Figure 6 shows Spearman's partial correlation coefficients between LTO and hourly average particle number and other pollutant concentrations. Controlling for meteorology and temporal variation, the correlation between hourly average PNCs and LTO was positive

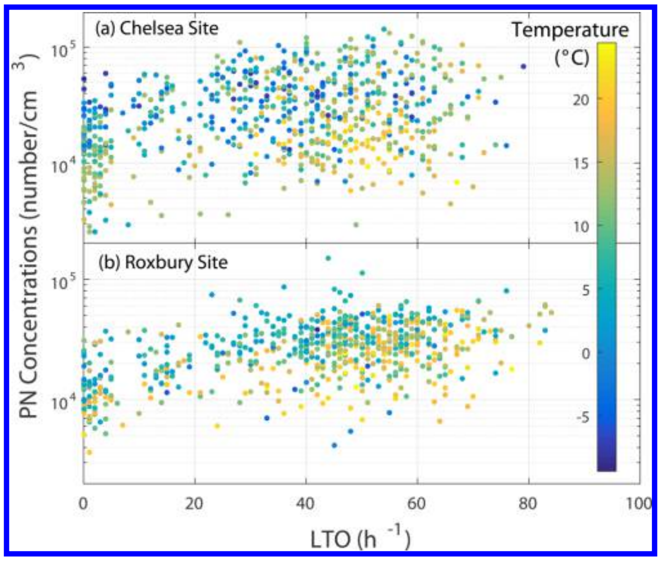


Figure 5. (a and b) Hourly average PNCs during impact-sector winds plotted against LTO for the Chelsea and Roxbury sites colored by ambient temperature (°C).

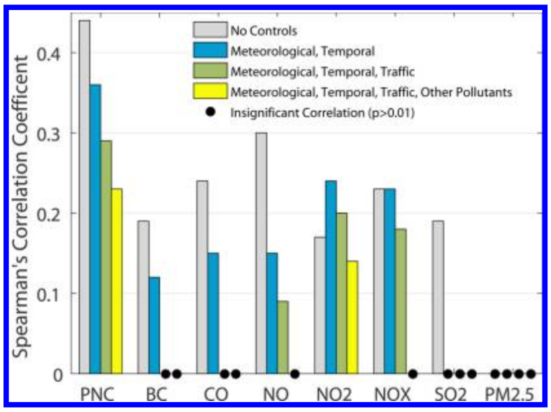


Figure 6. Spearman's partial correlation coefficients between LTO and hourly average pollutant concentrations at the Roxbury site controlling for different sets of variables (see Table S5 of the Supporting Information). Insignificant correlations ($p > 0.01$) are marked as black dots.

and significant ($r_s = 0.22$ and $p < 0.01$ for Chelsea, and $r_s = 0.36$ and $p < 0.01$ for Roxbury). Further, at the Roxbury site, controlling for concurrent traffic on I-93 as a proxy for local traffic, meteorology, and temporal variation, the correlation was still positive and significant ($r_s = 0.29$; $p < 0.01$). Likewise, using concurrent NO_x and CO as a proxy for local traffic emissions and controlling for meteorology and temporal variation, the correlation was also positive and significant ($r_s = 0.31$; $p < 0.01$). Additionally, controlling for $PM_{2.5}$ and ozone as well as traffic on I-93, the correlation was still positive and significant ($r_s = 0.23$; $p < 0.01$). Of the pollutants other than particle number, only oxides of nitrogen were significantly correlated with LTO after taking meteorology, temporal variation, and traffic on I-93 into account (r_s = 0.09, 0.20, and 0.18 for NO, NO_2, and NO_x, respectively; $p < 0.01$). Spearman's correlation coefficient values for hourly average PNCs, hourly average baseline PNCs, hourly median PNCs, and hourly average concentrations of other pollutants are summarized in Table S6 of the Supporting Information.

The impact-sector average BC concentration at the Roxbury site was somewhat higher than in other sectors [median concentration was 0.58 $\mu g/m^3$ (interquartile range of 0.39−1.0 $\mu g/m^3$) compared to 0.49 $\mu g/m^3$ (interquartile range of 0.30−0.79 $\mu g/m^3$); Mann−Whitney U test; $p < 0.01$], and although correlation with flight activity was significant after controlling for meteorology and temporal variation ($r_s = 0.12$; $p < 0.01$), it was not significant after additionally accounting for I-93 traffic ($r_s = 0.08$; $p = 0.023$). Concurrently measured $PM_{2.5}$ was not significantly correlated with LTO by itself or after controlling for meteorology and temporal variation or traffic.

Effect of the Wind Speed on PNCs. PNCs increased with wind speed for impact-sector winds but decreased with wind speed for winds from other directions (Figure 7). Highest PNCs for winds from other directions were observed during calm to <10 km h^{-1} winds. But during impact-sector winds, the highest PNCs were observed during 25−35 km h^{-1} winds at Chelsea (Figure 7a) and 30−50 km h^{-1} winds at Roxbury (Figure 7b). The increase in PNCs with wind speed was not due to increased flight activity: the average LTO was 41 ± 29% h^{-1} for wind speeds > 30 km h^{-1} and 41 ± 22% h^{-1} for wind speeds < 30 km h^{-1} in Figure 7d (see Figure S11 of the Supporting Information for LTO values).

Similar findings have been reported previously. Hsu et al.[19] reported maximum PNCs at 25 km h^{-1} winds at sites ≤ 500 m downwind of LAX, and Yu et al.[20] reported high values for SO_2 and NO/NO_x ratios during 25−35 km h^{-1} winds at a site 200 m downwind of LAX. Carslaw et al.[21] reported remarkably stable NO_x concentrations (only a 20% variation, as opposed to decreasing at higher speeds as is the case with roadway traffic emissions) at a site 180 m downwind of Heathrow Airport (London, U.K.) during 10.8−43.2 km h^{-1} winds and inferred that the source was buoyant aircraft exhaust plumes. Barrett et al.[22] simulated NO_x concentrations for the same site taking flight activity into account and suggested that the relatively fast arrival of buoyant exhaust plumes at higher wind speed counterbalances increased dilution. This explanation is consistent with buoyant-plume theory, which predicts that ground-level concentrations of pollutants downwind of large buoyant-plume sources (e.g., smoke stacks) will increase with wind speed up to a critical value at which maximum concentrations will occur.[23]

It is unlikely that other airport-related activities, such as ground support equipment and cargo transfer, and increased vehicular activity in the vicinity of the airport were the dominant source of elevated impact-sector PNCs. The impacts even from highly trafficked highways are widely reported to be limited to a few hundred meters of the roadway[3,10] and decrease at higher wind speed because dispersion of roadway emissions is proportional to wind speed.[23] However, given that these sources are located upwind in the impact sectors, some contribution, albeit continually waning at higher and higher wind speed, cannot be ruled out.

Higher PNCs were not observed for higher speed impact-sector winds during hours of reduced flight operations, likely because of considerably reduced LTO (i.e., during Hurricane Sandy on 10/28−29/2012 and the nor'easter storm on 02/08−09/2013, highlighted in Figure 7d and Figures S11−S14 of the Supporting Information). For example, coincident with the hours of lower PNCs during impact-sector winds on 10/29/2012, 0000−1459 h (Figure S13 of the Supporting Information), LTO was reduced to an average of 5 h^{-1} before full shutdown in the afternoon (2012 average for this period was 28.5 h^{-1}), while the traffic on I-93 during the same period was only about a third

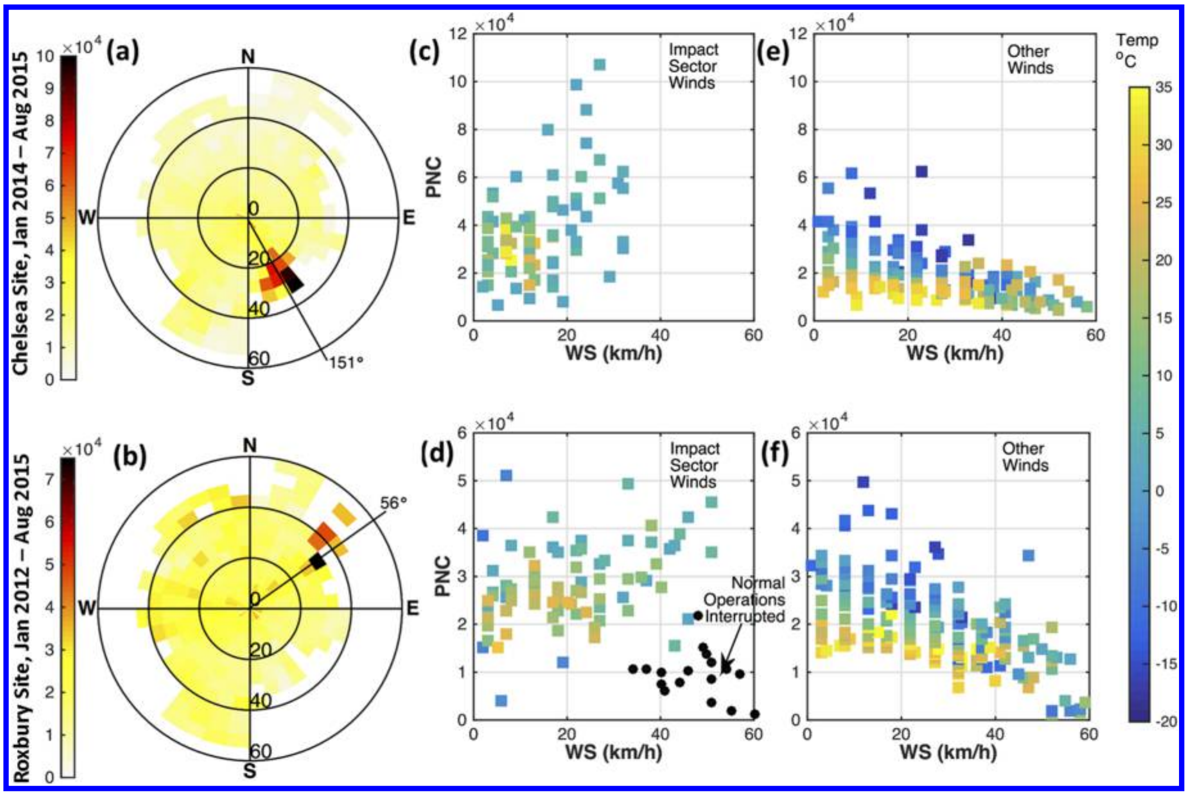


Figure 7. (a and b) PNC roses. The radial axis represents wind speed (km h^{-1}), and the angular coordinate represents wind direction. The azimuth angle of the airport from the sites is marked. (c−f) PNC dependence upon wind speed for impact-sector winds and all other directions. For visual clarity, hourly average PNCs were aggregated in 3.6 km h^{-1} (1 m s^{-1}) and 5 °C bins, and bin averages are plotted against wind speed. (d) Hours (not bin averages) corresponding to times when normal flight operations were interrupted by two extreme weather events are marked with black dots (also see Figures S11−S14 of the Supporting Information).

lower than the annual average (4200 compared to 6400 vehicles h^{-1}). Also, the average PNC for hours of no or trace rainfall (9300 ± 34%) was comparable to that during light−heavy rainfall (9600 ± 23%) during this period (Figure S14 of the Supporting Information), suggesting that PNC scavenging by rainfall was not significant. Atypical flight operation data from these two extreme weather events were not included in the statistical analysis.

Comparison of Particle Number and Other Pollutants Measured at the Roxbury Site. Pollutant roses for BC, CO, NO, NO_2, NO_x, $PM_{2.5}$, and SO_2 measured at the Roxbury site (panels a−c of Figure S10 of the Supporting Information) do not indicate elevated concentrations during impact-sector winds. The highest concentrations for all pollutants other than PNCs were observed during SSE winds, when the site was 20 m downwind of the nearest major street. Higher speed winds from impact sector had a diluting effect on concentrations of all pollutants other than particle number. As an example, NO_x concentration dependence upon wind speed is contrasted with PNCs in Figure 8, and other pollutants are shown in Figure S15 of the Supporting Information. The rates of concentration decrease with wind speed were comparable for impact-sector and non-impact-sector winds (Figure S16 of the Supporting Information).

Other pollutant concentrations were least correlated with PNCs during impact-sector winds (Figure S17 of the Supporting Information); i.e., Spearman's correlation coefficients during impact-sector winds were much lower than coefficients during winds that positioned the site downwind of the nearest major roadway (southeast) or highway (west). The difference in pollutant mixture between impact-sector and sectors impacted

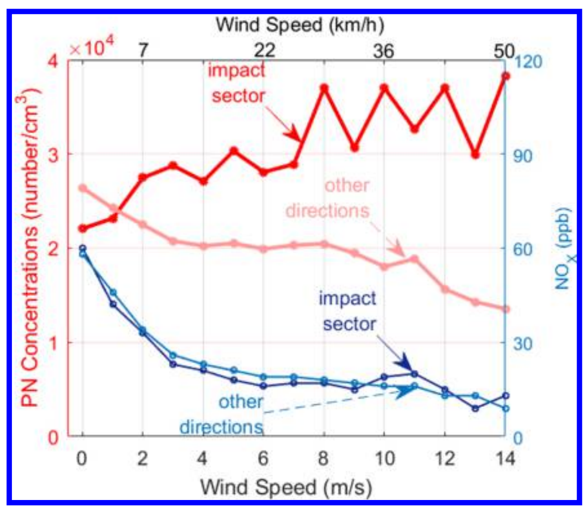


Figure 8. Wind speed dependence of PNCs and NO_x concentrations at the Roxbury site. See Figures S15 and S16 of the Supporting Information for other pollutants.

by local traffic emissions is further evidence that elevated impact-sector PNCs were likely not due to local traffic emissions.

The lack of distinct aircraft-related signals for other pollutants at Roxbury is generally consistent with the findings of previous studies. For example, the contribution from Heathrow emissions to annual average NO_x decreased from 27% at the airport boundary to 15% 2−3 km downwind,[21] and at sites 0.45−0.65 km downwind from a regional airport in Venice, Italy, NO_x concentrations (although significantly influenced by aircraft emissions) were driven primarily by local traffic emissions.[24] However, some impacts farther downwind from airports have also been reported. Dodson et al.[25] found that aircraft activity contributed 0.05−0.1 $\mu g/m^3$ (24−28%) of the total BC measured at five sites 0.16−3.7 km from a regional airport in Warwick, RI. At Hong Kong International Airport, Yu et al.[20] detected that aircraft emissions increased SO_2 and CO concentrations 3 km from the airport. Hudda et al.[4] reported an increase in both BC and NO_x up to 10 km for finer time resolution (1−30 s), mobile monitoring data; however, the flight activity at LAX is nearly twice that at Logan airport, and nearly 95% of it occurs on one set of trajectories. Our results suggest that, for pollutants other than UFPs, the airport-related signal was indistinguishable from the background 7.3 km downwind from the airport. However, it is also possible that the signal was masked in hourly aggregation of the data.

The long spatial range of PNC impacts may also be indicative of secondary particle formation. If organic and sulfur-containing constituents in aircraft-engine exhaust nucleate upon cooling, the net effect of secondary formation may exceed downwind dilution of PNCs, as opposed to the continual downwind dilution of relatively inert pollutants, such as CO or BC. PNCs are known to increase by as much as several orders of magnitude as a result of nucleation between the aircraft exhaust system and up to 30 m downwind.[26,27] Particles < 30 nm dominate the size distributions for individual aircraft plumes intercepted a few hundred meters from runways[28] and up to several kilometers downwind of airports[5] (particularly under flight trajectories[6]), which suggests that nucleation of fresh combustion emissions may continue over long downwind distances. Distant impacts are likely a mix of emissions from multiple thrust modes, which our data does not allow us to parse out, but a significant contribution from low-thrust-condition emissions (from idling or even landing) may promote particle formation because these emissions have a relatively high organic carbon content compared to high-thrust emissions (takeoffs), which have a relatively high BC content.[27,29]

Implications. Our results show that aviation emissions impact ambient PNCs in residential areas up to 7.3 km from Logan airport. At the Roxbury site, impact-sector winds were observed at 3.6% frequency in 2014 and their weighted contribution to the annual average PNC was 4.7%. At Chelsea (4.0 km from the airport), the weighted contribution of impact-sector winds to the annual average PNC was 10%, although such winds were observed at only 5.3% frequency in 2014. The impact is likely to be greater for nearby communities, such as Revere and Winthrop (Figure 1), that are downwind of the airport during SSW winds that occur for as much as a quarter of the time annually.

Finally, our analysis suggests that there is a need to take UFP concentrations into account in epidemiological studies of airport-related health effects, particularly for cardiovascular outcomes in the vicinity of airports. Such studies have tended to focus on the effect of noise[30,31] and have accounted for particulate mass ($PM_{2.5}$ or PM_{10}); however, particulate mass is a poor proxy for aircraft emissions compared to PNCs.[32,33] The case for UFPs can be made by calculating particle emission rates. In 2013, flight operations at Logan airport consumed 1.16×10^8 kg of Jet A fuel during taxiing, startup, takeoffs, and ascents up to 900 m[34] or about 26% of the city of Boston's estimated fuel consumption by all vehicles in that year.[35] However, particle number emission factors for aircraft exceed that of vehicles by an order of magnitude (e.g., Lobo et al.[28] reported aircraft emit 0.5−2.5 × 10^{17} particles/kg of fuel consumed during different thrust modes, and Perkins et al.[36] reported vehicles in Boston emit 1.4−4.9 × 10^{15} particles/kg of fuel consumed). As a result, the magnitudes for total emissions (emission factor × fuel consumption) from aircraft and vehicular traffic are comparable, suggesting that PNC exposure prediction in Boston (and similar cities) may be improved by incorporating aircraft as a source. Patton et al.[11,12] found that winds that included the airport as an upwind source accounted for nearly a tenth of the total variation explained by their PNC models for Somerville [7 km downwind of the airport (Figure 1)] and were also a significant explanatory variable for two other residential communities (Dorchester and Malden) in the greater Boston area. Similarly, Weichenthal et al.[37] found that distance to Pearson International Airport (Toronto, Ontario, Canada) was an important PNC predictor after accounting for roadways. Inclusion of variables that can further characterize aviation impacts (e.g., active runway direction and distance during prevailing winds) and inclusion of temporal indicators of flight activity may enhance predictive capabilities of models.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.6b01815.

Information related to flight activity at Logan International Airport, details of monitoring sites and instruments, distributions of variables, traffic volume data and fits, additional graphics related to PNC trends at monitoring sites and the effect of wind speed on pollutant concentrations, and correlation coefficient values (PDF)

■ AUTHOR INFORMATION

Corresponding Author

*Telephone: 617-627-5489. Fax: 617-627-3994. E-mail: john.durant@tufts.edu.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

Field work was conducted by Jessica Perkins, Alex Bob, Joanna Stowell, and Hanaa Rohman. The authors thank The Neighborhood Developers (Chelsea, MA), Massachusetts Department of Environmental Protection (Roxbury, MA), and Boston Globe (Dorchester, MA) for providing space and electricity for our monitoring equipment. Flight activity data for Logan International Airport was provided by Massachusetts Port Authority. The authors are grateful to the anonymous reviewers for the thoughtful commentary that improved the manuscript. This work was funded by National Institutes of Health (NIH)−National Heart, Lung, and Blood Institute (NHLBI) Grant CA148612 to the University of Massachusetts Lowell, NIH−National Institute of Environmental Health Sciences (NIEHS) Grant ES015462 to Tufts University, and the Somerville Transportation Equity Partnership (STEP).

■ REFERENCES

(1) Health Effects Institute (HEI). *HEI Review Panel on Ultrafine Particles. Understanding the Health Effects of Ambient Ultrafine Particles. HEI Perspectives 3*; HEI: Boston, MA, 2013.

(2) Delfino, R. J.; Sioutas, C.; Malik, S. Potential Role of Ultrafine Particles in Associations between Airborne Particle Mass and

Cardiovascular Health. *Environ. Health Perspect.* **2005**, *113* (8), 934−946.
(3) Brugge, D.; Durant, J. L.; Rioux, C. Near-highway pollutants in motor vehicle exhaust: A review of epidemiologic evidence of cardiac and pulmonary health risks. *Environ. Health* **2007**, *6* (1), 23.
(4) Hudda, N.; Gould, T.; Hartin, K.; Larson, T. V.; Fruin, S. A. Emissions from an international airport increase particle number concentrations 4-fold at 10 km downwind. *Environ. Sci. Technol.* **2014**, *48* (12), 6628−6635.
(5) Keuken, M. P.; Moerman, M.; Zandveld, P.; Henzing, J. S.; Hoek, G. Total and size-resolved particle number and black carbon concentrations in urban areas near Schiphol airport (the Netherlands). *Atmos. Environ.* **2015**, *104*, 132−142.
(6) Hudda, N.; Fruin, S. A. International Airport Impacts to Air Quality: Size and Related Properties of Large Increases in Ultrafine Particle Number Concentrations. *Environ. Sci. Technol.* **2016**, *50* (7), 3362−3370.
(7) Fuller, C. H.; Williams, P. L.; Mittleman, M. A.; Patton, A. P.; Spengler, J. D.; Brugge, D. Response of biomarkers of inflammation and coagulation to short-term changes in central site, local, and predicted particle number concentrations. *Ann. Epidemiol.* **2015**, *25* (7), 505−511.
(8) Lane, K. J.; Levy, J. I.; Scammell, M. K.; Patton, A. P.; Durant, J. L.; Mwamburi, M.; Zamore, W.; Brugge, D. Effect of time-activity adjustment on exposure assessment for traffic-related ultrafine particles. *J. Exposure Sci. Environ. Epidemiol.* **2015**, *25* (5), 506−516.
(9) Ostro, B.; Lipsett, M.; Reynolds, P.; Goldberg, D.; Hertz, A.; Garcia, C.; Henderson, K. D.; Bernstein, L. Long-term exposure to constituents of fine particulate air pollution and mortality: Results from the California Teachers Study. *Environ. Health Perspect.* **2009**, *118* (3), 363−369.
(10) Karner, A. A.; Eisinger, D. S.; Niemeier, D. A. Near-roadway air quality: Synthesizing the findings from real-world data. *Environ. Sci. Technol.* **2010**, *44* (14), 5334−5344.
(11) Patton, A. P.; Collins, C.; Naumova, E. N.; Zamore, W.; Brugge, D.; Durant, J. L. An hourly regression model for ultrafine particles in a near-highway urban area. *Environ. Sci. Technol.* **2014**, *48* (6), 3272−3280.
(12) Patton, A. P.; Zamore, W.; Naumova, E. N.; Levy, J. I.; Brugge, D.; Durant, J. L. Transferability and generalizability of regression models of ultrafine particles in urban neighborhoods in the boston area. *Environ. Sci. Technol.* **2015**, *49* (10), 6051−6060.
(13) Fuller, C. H.; Patton, A. P.; Lane, K.; Laws, M. B.; Marden, A.; Carrasco, E.; Spengler, J.; Mwamburi, M.; Zamore, W.; Durant, J. L.; Brugge, D. A community participatory study of cardiovascular health and exposure to near-highway air pollution: Study design and methods. *Rev. Environ. Health* **2013**, *28* (1), 21−35.
(14) Tucker, K. L.; Mattei, J.; Noel, S. E.; Collado, B. M.; Mendez, J.; Nelson, J.; Griffith, J.; Ordovas, J. M.; Falcon, L. M. The Boston Puerto Rican Health Study, a longitudinal cohort study on health disparities in Puerto Rican adults: Challenges and opportunities. *BMC Public Health* **2010**, *10* (1), 107.
(15) Hanna, S.; Hendrick, E. *Analysis of Annual Wind Roses and Precipitation within about 50 Miles of the Pilgrim Nuclear Power Station, and Use of CALMET To Calculate the Annual Distribution of Trajectories from the Pilgrim Station*; Hanna Consultants: Kennebunkport, ME, 2011.
(16) National Centers for Environmental Information (NCEI). *Automated Surface Observing System (ASOS)*; NCEI: Asheville, NC, 2016; https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/automated-surface-observing-system-asos (accessed March 19, 2016).
(17) United States Environmental Protection Agency (U.S. EPA). *Air Quality System Data Mart*; U.S. EPA: Washington, D.C., 2016; http://www.epa.gov/ttn/airs/aqsdatamart (accessed March 19, 2016).
(18) Massachusetts Department of Transportation. *Stakeholder HERE Application*; Massachusetts Department of Transportation: Boston, MA, 2016; http://www.trafficsensors.ext.here.com (accessed March 19, 2016).
(19) Hsu, H.-H.; Adamkiewicz, G.; Houseman, E. A.; Zarubiak, D.; Spengler, J. D.; Levy, J. I. Contributions of aircraft arrivals and departures to ultrafine particle counts near Los Angeles International Airport. *Sci. Total Environ.* **2013**, *444*, 347−355.
(20) Yu, K. N.; Cheung, Y. P.; Cheung, T.; Henry, R. C. Identifying the impact of large urban airports on local air quality by nonparametric regression. *Atmos. Environ.* **2004**, *38* (27), 4501−4507.
(21) Carslaw, D. C.; Beevers, S. D.; Ropkins, K.; Bell, M. C. Detecting and quantifying aircraft and other on-airport contributions to ambient nitrogen oxides in the vicinity of a large international airport. *Atmos. Environ.* **2006**, *40* (28), 5424−5434.
(22) Barrett, S. R. H.; Britter, R. E.; Waitz, I. A. Impact of aircraft plume dynamics on airport local air quality. *Atmos. Environ.* **2013**, *74*, 247−258.
(23) Seinfeld, J. H.; Pandis, S. N. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*, 2nd ed.; Wiley-Interscience: Hoboken, NJ, 2006
(24) Valotto, G.; Varin, C. Characterization of hourly NO_x atmospheric concentrations near the Venice International Airport with additive semi-parametric statistical models. *Atmos. Res.* **2016**, *167*, 216−223.
(25) Dodson, R. E.; Andres Houseman, E.; Morin, B.; Levy, J. I. An analysis of continuous black carbon concentrations in proximity to an airport and major roadways. *Atmos. Environ.* **2009**, *43* (24), 3764−3773.
(26) Wey, C. C.; Anderson, B. A.; Wey, C.; Miake-Lye, R. C.; Whitefield, P.; Howard, R. Overview on the Aircraft Particle Emissions Experiment (APEX). *J. Propul. Power* **2007**, *23* (5), 898−905.
(27) Timko, M. T.; Fortner, E.; Franklin, J.; Yu, Z.; Wong, H. W.; Onasch, T. B.; Miake-Lye, R. C.; Herndon, S. C. Atmospheric measurements of the physical evolution of aircraft exhaust plumes. *Environ. Sci. Technol.* **2013**, *47* (7), 3513−3520.
(28) Lobo, P.; Hagen, D. E.; Whitefield, P. D.; Raper, D. PM emissions measurements of in-service commercial aircraft engines during the Delta-Atlanta Hartsfield Study. *Atmos. Environ.* **2015**, *104*, 237−245.
(29) Herndon, S. C.; Onasch, T. B.; Frank, B. P.; Marr, L. C.; Jayne, J. T.; Canagaratna, M. R.; Grygas, J.; Lanni, T.; Anderson, B. E.; Worsnop, D.; Miake-Lye, R. C. Particulate emissions from in-use commercial aircraft. *Aerosol Sci. Technol.* **2005**, *39* (8), 799−809.
(30) Hansell, A. L.; Blangiardo, M.; Fortunato, L.; Floud, S.; de Hoogh, K.; Fecht, D.; Ghosh, R. E.; Laszlo, H. E.; Pearson, C.; Beale, L.; Beevers, S.; Gulliver, J.; Best, N.; Richardson, S.; Elliott, P. Aircraft noise and cardiovascular disease near Heathrow airport in London: Small area study. *BMJ* **2013**, *347* (oct08_3), f5432.
(31) Correia, A. W.; Peters, J. L.; Levy, J. I.; Melly, S.; Dominici, F. Residential exposure to aircraft noise and hospital admissions for cardiovascular diseases: Multi-airport retrospective study. *BMJ* **2013**, *347* (oct08_3), f5561.
(32) Corbin, J. C. PM0.1 particles from aircraft may increase risk of vascular disease. *BMJ* **2013**, *347* (nov19_19), f6783.
(33) Hansell, A. L.; Gulliver, J.; Beevers, S.; Elliott, P. Authors' reply to Corbin, Moore, and Coebergh. *BMJ* **2013**, *347* (nov19_15), f6795.
(34) Massachusetts Port Authority. *S. & B. P. U. Environmental Development Report, Logan International Airport, 2012/2013*; Massachusetts Port Authority: Boston, MA, 2013.
(35) City of Boston. *Community Greenhouse Gas Inventory 2005−2013*; City of Boston: Boston, MA, 2014.
(36) Perkins, J. L.; Padró-Martínez, L. T.; Durant, J. L. Particle number emission factors for an urban highway tunnel. *Atmos. Environ.* **2013**, *74*, 326−337.
(37) Weichenthal, S.; Van Ryswyk, K.; Goldstein, A.; Bagg, S.; Shekkarizfard, M.; Hatzopoulou, M. A land use regression model for ambient ultrafine particles in Montreal, Canada: A comparison of linear regression and a machine learning approach. *Environ. Res.* **2016**, *146*, 65−72.

Environment International 92–93 (2016) 173–182

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Association of modeled long-term personal exposure to ultrafine particles with inflammatory and coagulation biomarkers

Kevin J. Lane [a,b,*], Jonathan I. Levy [a], Madeleine K. Scammell [a], Junenette L. Peters [a], Allison P. Patton [c,d], Ellin Reisner [e], Lydia Lowe [f], Wig Zamore [e], John L. Durant [c], Doug Brugge [c,g,h]

[a] Department of Environmental Health, Boston University School of Public Health, Boston, MA, United States
[b] Yale University School of Forestry & Environmental Studies, 195 Prospect Street, New Haven, CT, United States
[c] Department of Civil and Environmental Engineering, Tufts University, Medford, MA, United States
[d] Environmental and Occupational Health Sciences Institute, Rutgers University, Piscataway, NJ, United States
[e] Somerville Transportation Equity Partnership, Somerville, MA, United States
[f] Chinese Progressive Association, Boston, MA, United States
[g] Department of Public Health and Community Medicine, Tufts University School of Medicine, Boston, MA, United States
[h] Jonathan M. Tisch College of Citizenship and Public Service

ARTICLE INFO

Article history:
Received 13 October 2015
Received in revised form 13 March 2016
Accepted 14 March 2016
Available online xxxx

Keywords:
Ultrafine particles
Time-activity
Systemic inflammation
Particle number concentration
Cardiovascular risk

ABSTRACT

Background: Long-term exposure to fine particulate matter has been linked to cardiovascular disease and systemic inflammatory responses; however, evidence is limited regarding the effects of long-term exposure to ultrafine particulate matter (UFP, <100 nm). We used a cross-sectional study design to examine the association of long-term exposure to near-highway UFP with measures of systemic inflammation and coagulation.

Methods: We analyzed blood samples from 408 individuals aged 40–91 years living in three near-highway and three urban background areas in and near Boston, Massachusetts. We conducted mobile monitoring of particle number concentration (PNC) in each area, and used the data to develop and validate highly resolved spatiotemporal (hourly, 20 m) PNC regression models. These models were linked with participant time-activity data to determine individual time-activity adjusted (TAA) annual average PNC exposures. Multivariable regression modeling and stratification were used to assess the association between TAA-PNC and single peripheral blood measures of high-sensitivity *C*-reactive protein (hsCRP), interleukin-6 (IL-6), tumor-necrosis factor alpha receptor II (TNFRII) and fibrinogen.

Results: After adjusting for age, sex, education, body mass index, smoking and race/ethnicity, an interquartile-range (10,000 particles/cm^3) increase in TAA-PNC had a positive non-significant association with a 14.0% (95% CI: −4.6%, 36.2%) positive difference in hsCRP, an 8.9% (95% CI: −0.4%, 10.9%) positive difference in IL-6, and a 5.1% (95% CI: −0.4%, 10.9%) positive difference in TNFRII. Stratification by race/ethnicity revealed that TAA-PNC had larger effect estimates for all three inflammatory markers and was significantly associated with hsCRP and TNFRII in white non-Hispanic, but not East Asian participants. Fibrinogen had a negative non-significant association with TAA-PNC.

Conclusions: Our findings suggest an association between annual average near-highway TAA-PNC and subclinical inflammatory markers of CVD risk.

1. Introduction

Studies have shown associations of proximity to traffic with excess cardiovascular disease (CVD) risk and increases in biomarkers of systemic inflammation such as high sensitivity *C*-reactive protein (hsCRP) and interleukin-6 (IL-6) (Brugge et al., 2007; Hoffmann et al., 2009; Williams et al., 2009; Lanki et al., 2015; Brugge et al., 2013). Proximity may be a surrogate for exposure to traffic-related air pollutants (TRAPs) such as nitrogen oxides (NOx), nitrogen dioxide, black carbon, particulate matter <10 μm (PM_{10}), and ultrafine particles (UFP, <100 nm). Concentrations of these pollutants have been shown to be substantially elevated next to major roadways and highways (Karner et al., 2010; Padró-Martínez et al., 2012; Patton et al., 2014a).

Previous studies have associated UFP exposure with systemic inflammation and increased CVD risk. Animal studies show that UFP can promote inflammatory responses in the lungs as well as translocate to the circulatory system. This can lead to increases in atherosclerotic lesions, upregulation of genes for anti-oxidant responses to oxidative stress, and decreases in anti-inflammatory high density lipoprotein (Araujo et al., 2008; Araujo and Nel, 2009). Controlled human exposure

* Corresponding author at: Yale School of Forestry & Environmental Studies, 195 Prospect Street, New Haven, CT 06511, United States.
E-mail address: kevin.lane@yale.edu (K.J. Lane).

http://dx.doi.org/10.1016/j.envint.2016.03.013

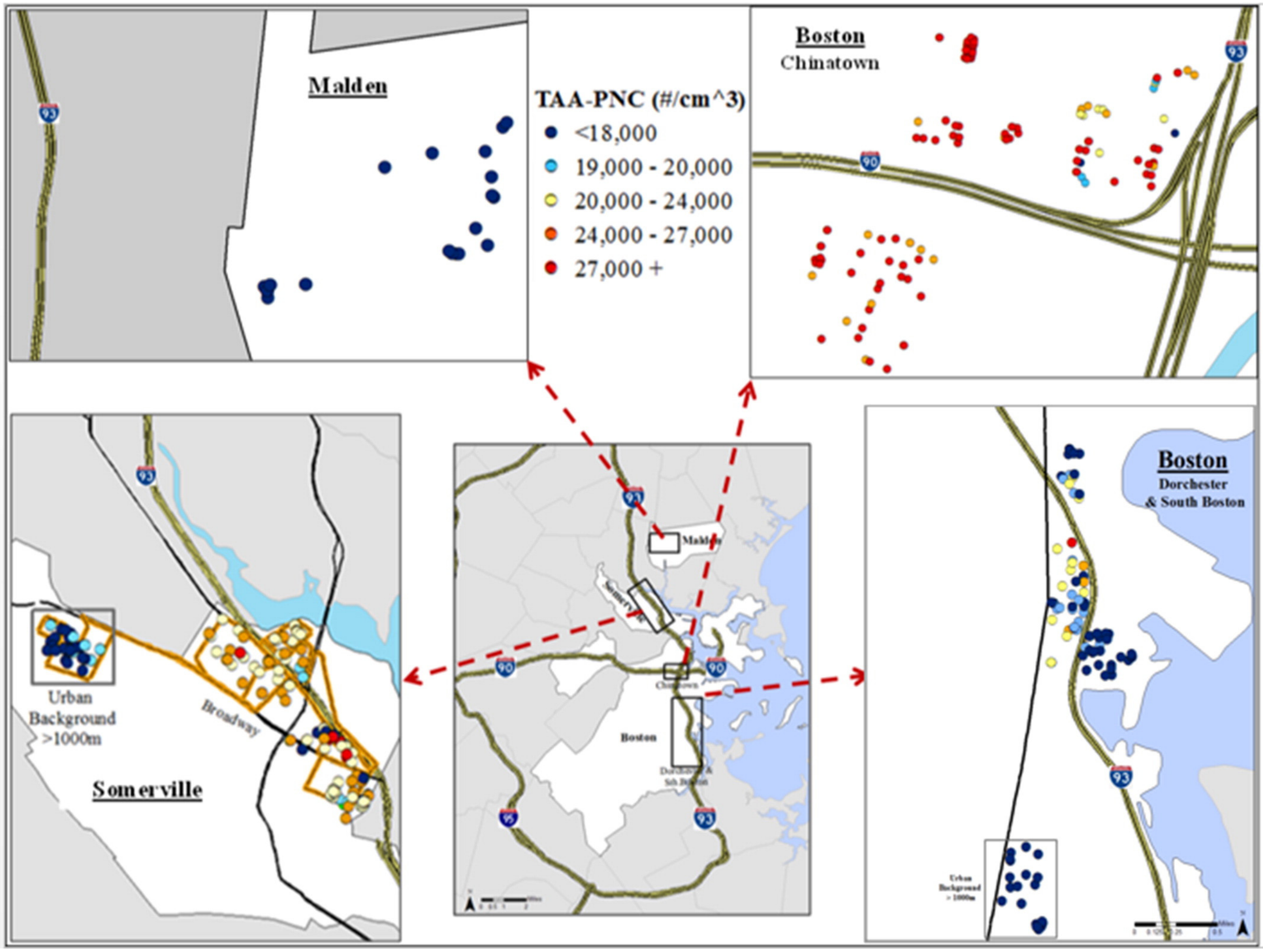


Fig. 1. Time-activity adjusted annual average particle number concentration (TAA-PNC) by study area.

studies of UFP found associations with inflammatory and coagulation responses in the lungs as well as in peripheral blood (Devlin et al., 2014; Nemmar et al., 2002; Samet et al., 2009). Panel studies on short-term effects of particle number concentration (PNC) have reported increases in CRP, IL-6, tumor-necrosis factor alpha receptor II (TNFRII) and markers of coagulation such as *D*-dimer and von Willebrand Factor (vWF) with same day UFP exposure and up to three-week lags (Delfino et al., 2008; Hertel et al., 2010; Fuller et al., 2015). One study reported significant associations with hsCRP and a suggestive association with fibrinogen (Ruckerl et al., 2014).

The few studies on the cardiovascular effects of long-term exposure (e.g., ≥ 1 year) to individual TRAPs have produced inconsistent results (Gan et al., 2011; Gan et al., 2014). In particular, until recently, there had been little evidence for effects of long-term UFP exposure on cardiovascular health, in part due to exposure modeling constraints. A study of the California Teachers Study Cohort (Ostro et al., 2015) found a significant association of long-term exposure to UFP mass and constituents with all-cause, CVD, and ischemic heart disease mortality. Exposure was estimated with a chemical transport model at 4 × 4 km resolution. A study using another chemical transport model to examine multiple PM sizes at 1 × 1 km resolution (Viehmann et al., 2015) found that long-term exposure to UFP was significantly associated with hsCRP and fibrinogen in crude models, and positively but insignificantly associated in adjusted models. While both studies found associations with long-term UFP, they utilized PNC models that could not capture within neighborhood (<1 × 1 km) near roadway PNC variability.

To our knowledge, there are no published studies that used intensive local monitoring of PNC to build highly spatiotemporally-resolved UFP models (20 m, hourly) and combined them with individual time-activity patterns in an epidemiological study. Assigning area ambient annual average at the residence introduces exposure misclassification for pollutants such as UFP that have high spatial and temporal variability (Buonanno et al., 2014; Gu et al., 2015; Lane et al., 2015). Given the substantial spatial and temporal variability of near roadway UFP concentrations in urban areas, highly resolved UFP exposure assessment should improve long-term epidemiological studies (HEI, 2013; Sioutas et al., 2005).

Our objectives were to develop individualized annual UFP exposure estimates and to evaluate associations with hsCRP, IL-6, TNFRII, and fibrinogen. These analyses were performed within the Community Assessment of Freeway Exposure and Health (CAFEH) study, a hypothesis driven cross-sectional, community based participatory research (CBPR) study evaluating cardiovascular health risks from exposure to UFP in near-roadway populations. We report here the association of annual average exposure to high resolution time activity adjusted (TAA) PNC with hsCRP, IL-6, TNFRII, and fibrinogen for study participants living in neighborhoods in the Boston area (Massachusetts, USA).

2. Material and methods

2.1. CAFEH study population

Participant recruitment was performed concurrently with air pollution monitoring in near-highway (≤500 m from Interstate Highways 90 and 93) and urban background areas (≥1000 m from Interstate Highways) including Somerville, Malden, and the Boston neighborhoods of Dorchester, South Boston, and Chinatown (Fig. 1). Individuals 40+ years of age completed an informed consent after being recruited in each neighborhood using a geographically-weighted, random-selection process, supplemented by a convenience sample of participants from senior housing developments in Dorchester and Somerville. The analysis reported here is of those participants who had a viable peripheral blood sample on all biomarkers and complete survey data ($n = 408$), of whom 327 were from the random sample and 81 were from the convenience sample. Details on study recruitment, questionnaire, clinics, blood storage and inflammatory assays have been previously published (Fuller et al., 2014). Here we present a brief summary, with more detail provided in Supplemental Text 1.

Recruitment was conducted in Somerville (near highway = 101 participants; urban background = 25 participants) from July 2009 to May 2010, in Dorchester (near highway = 75 participants; urban background = 21 participants) and South Boston (near highway = 15 participants) from September 2010 to April 2011, and in Chinatown (near highway = 133 participants) and its paired urban background neighborhood, Malden (40 participants), from June 2011 to February 2012. Recruitment of participants from high-rise buildings (only present in Chinatown) was restricted to residents who lived on one of the first four floors since we found no significant vertical differences in PNC up to 35 m (Wu et al., 2014).

Participants completed an in-home survey that included questions about demographics (e.g., age, sex, education, income, race/ethnicity, and employment status), recent illnesses, major cardiovascular diseases, hypertension, use of statins, insulin, or oral hypoglycemics, smoking status, and micro-environment time-activity. Peripheral blood was drawn at study clinics by registered nurses and analyzed for biomarkers using standard protocols. We measured height and weight for calculation of body mass index (BMI; in kg/m^2).

Geocoding of participant addresses was performed using a multi-stage process that included address verification by field staff during home visits. This was followed by parcel and street network geocoding accompanied by manual correction via orthophotos and apartment/multi-unit floor plans to reduce positional error (Lane et al., 2013; Brugge et al., 2013). We used ESRI ArcGIS v10.1 (ESRI, Redlands CA) software for all geographic information system (GIS) processes.

2.2. PNC monitoring, modeling and exposure assignment

Details on PNC monitoring, regression modeling and time-activity adjusted exposure assignment have been published (Padró-Martínez et al., 2012, Patton et al., 2014b; Patton et al., 2015; Lane et al., 2015). Here we present a brief summary with more detail in Supplemental Text 2. The Tufts Air Pollution Monitoring Laboratory (TAPL), a converted recreational vehicle equipped with fast-response monitoring instruments, was used to measure air pollutants. The TAPL was repeatedly driven over fixed routes in each study area during a range of hours of the day, days of the week and seasons. UFP were measured by a condensation particle counter (TSI Model 3775) as particle number concentration (PNC, 4–3000 nm). Multivariable regression modeling was used to build predictive models to estimate hourly natural log (LN) PNC at locations within the study areas. The PNC regression models utilized both spatial (side of and distance to highway, distance to nearest major road) and temporal (wind speed, wind direction, temperature, day of week, highway traffic volume and speed) variables to predict values. The models were used to estimate ambient PNC at the residence of each participant for each hour of the year during which air monitoring was performed.

These estimates of exposure to PNC were adjusted for time-activity based on survey data to reflect the amount of time participants spent in each of the five micro-environments (details in Lane et al., 2013 and Supplemental Text 2). Time-activity questions were used to assign hourly locations for the most recent weekday and weekend for unemployed participants and for the most recent workday and non-workday for employed participants. Time was assigned by microenvironments in one-hour increments for (i) inside homes, (ii) outside homes, (iii) work/school, (iv) other non-highway locations, and (v) time on highways. Micro-environment time-activity data was found to be consistent in a subset of participants ($n = 169$) that completed a second questionnaire an average of 5.4 months after the initial questionnaire and resulted in less than an hour of mean difference in microenvironment time allocation. We assigned exposures to each participant for every hour of the air monitoring year. We also adjusted for infiltration of PNC into residences (Fuller et al., 2013).

2.3. Statistical analysis

We evaluated associations of biomarkers (hsCRP, IL-6, TNFRII, and fibrinogen) with TAA-PNC. Because three of the biomarkers (hsCRP, IL-6 and TNFRII) were not normally distributed, they were first log-transformed. Fibrinogen was normally distributed, but also examined as a percent change for association with TAA-PNC to be consistent with

Table 1
Population characteristics with viable blood samples and complete data on covariates ($n = 408$).

Characteristic	n	% or mean ± SD
Age (years, mean ± SD)	408	61 ± 13
BMI (kg/m^2, mean ± SD)	408	27.4 ± 6.8
Underweight (<18.5)	14	3%
Normal weight (18.5–24.9)	168	41%
Overweight (25–29.9)	117	29%
Obese (30+)	109	27%
City/neighborhood		
Near highway (≤500 m)		
Somerville	100	24%
Dorchester/South Boston	90	22%
Chinatown	133	32%
Urban background (≥1000 m)		
Somerville	25	6%
Dorchester/South Boston	20	5%
Malden	40	10%
Sex		
Female	238	58%
Male	170	42%
Smoking		
Current	83	20%
Former	126	31%
Never	199	49%
Educational attainment		
<High school diploma	136	34%
High school diploma	123	30%
Undergraduate	99	24%
Graduate school	50	12%
Race/ethnicity		
White non-Hispanic	173	42%
East Asian	162	40%
Other	73	18%
Born in US		
Yes	179	44%
No	229	56%
Statin medication		
Yes	114	28%
No	294	72%
Diabetes medication		
Yes	33	9%
No	375	91%

the other biomarkers. Generalized linear models (GLMs) were used to test the association of TAA-PNC with LN hsCRP, LN IL-6, LN TNFRII (hereafter referred to as hsCRP, IL-6 and TNFRII) as well as fibrinogen. We approached interpretation of statistical outcomes based on 95% confidence intervals, with effect estimates. Estimates are reported as percent change in inflammatory biomarker levels for an interquartile-range (IQR) change in TAA-PNC. Statistical analyses were performed using SAS (Statistical Analysis Software, Cary, North Carolina) version 9.1.2.

We started with univariate analysis for association between TAA-PNC and each biomarker. Regression analyses were then adjusted for age (years), sex (female, male), BMI (continuous, as kg/m^2), smoking status (current, former, never), educational attainment (less than high school, high school diploma, undergraduate degree, graduate degree), race/ethnicity (detailed below) and nativity (born in the United States (US): yes, no). These variables are all known to be cardiovascular disease risk factors and/or predictors of some of our biomarkers of interest (McDade et al., 2011), including nativity (Corlin et al., 2014). For race/ethnicity, we had a large non-Hispanic white population and a large Chinese and Vietnamese population due to our recruitment in Chinatown, with more limited numbers for other racial/ethnic groups. Therefore, we grouped race/ethnicity into non-Hispanic white, East Asian (Chinese and Vietnamese), and other (African American, Haitian-Creole, white-Hispanic, Latino, Indian, Pakistani, Pacific Islander and Native American), a heterogeneous group comprised of multiple race/ethnicities each of limited sample size. Race/ethnicity and nativity were highly correlated with one another. For example, 100% of the East Asian participants were foreign born. Accordingly, we developed regression models to examine effects of race/ethnicity and nativity separately while adjusting for the other cardiovascular risk factors. Additionally, the differences in both TAA-PNC exposure concentrations and inflammatory markers between East Asian and white non-Hispanic populations led us to conduct a stratified analysis between these two groups.

2.4. Additional analysis

Sensitivity analyses were performed to examine potential effects of additional variables and constraints on the relationship between TAA-PNC and the biomarkers. We tested BMI as a categorical term in place of the linear term as: 1) underweight (≤18.5 kg/m^2) and normal weight (18.6–24.9 kg/m^2), combined due to low sample size in the underweight group; 2) overweight (25–29.9 kg/m^2); and 3) obese (≥30 kg/m^2). We also considered a quadratic term along with the continuous linear term to account for potential U-shaped associations. We evaluated the effects of including statin medication use, diabetes medication use (insulin or oral hypoglycemic), personal income in place of education, season of blood sample, and neighborhood in our models. We also stratified by CVD risk factors age, sex, BMI, nativity, race/ethnicity, smoking status, diabetes and statin medications. Additional stratification was by random vs. convenience sample and distance from highway. Because the exposure regression model predicted LN-transformed PNC at the residence, we

Table 2
Distribution of biomarkers of systemic inflammation (high sensitivity *C*-reactive protein, (hsCRP), interleukin-6 (IL-6) and tumor necrosis factor alpha receptor II (TNFRII)) and coagulation (fibrinogen) by population characteristics.

Characteristic	hsCRP (mg/L)	IL-6 (pg/mL)	TNFRII (pg/mL)	Fibrinogen (mg/dL)
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
Total	1.27 (2.77)	1.28 (1.43)	2244 (1118)	448 (132)
City/neighborhood				
Near highway (<500 m)				
Somerville	2.02 (2.77)	1.74 (2.20)	2761 (1425)	470 (133)
Dorchester/South Boston	1.47 (3.91)	1.75 (1.92)	2155 (1018)	467 (124)
Chinatown	0.71 (1.63)	1.07 (0.90)	2004 (950)	425 (116)
Urban background (≥1000 m)				
Somerville	0.94 (1.02)	0.95 (0.87)	2252 (876)	410 (76)
Dorchester/South Boston	2.16 (5.40)	1.38 (1.31)	2137 (1038)	476 (287)
Malden	0.82 (1.32)	1.14 (0.78)	2315 (908)	492 (112)
Sex				
Female	1.18 (2.72)	1.22 (1.38)	2212 (1146)	456 (133)
Male	1.29 (2.73)	1.39 (1.56)	2349 (1001)	440 (131)
Age (quartiles)				
40–50 years	0.95 (2.06)	1.01 (1.10)	2100 (777)	424 (103)
51–60 years	1.58 (2.77)	1.22 (1.50)	2383 (778)	431 (137)
61–71 years	1.28 (2.79)	1.34 (1.80)	2509 (1199)	473 (120)
72–91 years	1.34 (2.83)	1.52 (1.71)	2762 (1334)	480 (147)
Smoking				
Current	1.40 (3.25)	1.44 (1.66)	2420 (1037)	460 (150)
Former	1.59 (2.78)	1.49 (2.06)	2440 (1427)	459 (140)
Never	0.91 (1.82)	1.16 (1.11)	2103 (1077)	439 (124)
Body mass index (kg/m^2)				
Under & normal weight (≤24.9)	0.66 (1.44)	1.01 (0.79)	2006 (846)	425 (114)
Overweight (25–29.9)	1.45 (2.26)	1.47 (1.47)	2462 (1012)	443 (116)
Obese (30+)	2.73 (4.71)	1.97 (2.25)	2590 (1517)	510 (179)
Race/ethnicity				
White non-Hispanic	1.61 (3.0)	1.63 (2.00)	2520 (1257)	454 (133)
East Asian	0.72 (1.53)	1.07 (0.80)	2042 (943)	435 (132)
Other	2.04 (4.06)	1.56 (1.39)	2183 (978)	473 (133)
Born in US				
Yes	1.81 (3.16)	1.69 (2.17)	2473 (1271)	467 (137)
No	0.82 (1.73)	1.14 (1.04)	2102 (1024)	439 (123)
Statin medication				
Yes	2.48 (5.51)	2.01 (2.41)	2775 (1634)	544 (151)
No	1.11 (2.10)	1.89 (1.24)	2176 (1005)	457 (124)
Diabetes medication				
Yes	2.06 (4.02)	1.75 (1.68)	2553 (1895)	506 (152)
No	1.27 (2.71)	1.31 (1.38)	2589 (1097)	447 (129)

Table 3
Distribution of time-activity adjusted annual average particle number concentration (TAA-PNC) by distance to highway groups and demographic variables.

Characteristic	TAA-PNC (10^4 particles/cm^3)[a]		
	Median	IQR	Min–max
Total	2.3	1.0	0.9–3.5
City/neighborhood			
Near highway (≤500 m)			
Somerville	2.4	0.3	2.0–3.1
Dorchester/South Boston	1.8	0.4	1.1–2.8
Chinatown	2.8	0.4	1.7–3.5
Urban background (≥1000 m)			
Somerville	1.8	0.2	1.6–2.0
Dorchester/South Boston	1.3	0.3	1.0–1.6
Malden	1.0	0.1	0.9–1.2
Sex			
Female	2.3	0.9	0.9–3.4
Male	2.2	1.1	0.9–3.5
Age (quartiles)			
40–50 years	2.2	0.9	0.9–3.3
51–60 years	2.3	0.8	1.0–3.3
61–71 years	2.2	1.2	0.9–3.4
72–91 years	2.6	1.0	0.9–3.5
Smoking			
Current	2.4	1.1	0.9–3.5
Former	2.2	0.8	0.9–3.2
Never	2.1	0.8	0.9–3.1
Body mass index (kg/m^2)			
Under & normal weight (≤24.9)	2.4	1.0	0.9–3.5
Overweight (25–29.9)	2.4	0.9	0.9–3.4
Obese (30+)	2.1	0.9	0.9–3.0
Education			
Less than high school diploma	2.6	0.7	0.9–3.5
High school diploma	2.4	0.9	0.9–3.4
Undergraduate	2.0	1.0	0.9–3.1
Graduate school	1.8	0.7	0.9–3.0
Race/ethnicity			
White non-Hispanic	2.0	0.7	0.9–3.1
East Asian	2.8	0.7	0.9–3.5
Other	2.2	0.7	1.0–3.1
Born in US			
Yes	2.0	0.8	0.9–3.1
No	2.6	0.8	0.9–3.5

[a] Significant figures for PNC are to the 0.1×10^4.

also evaluated associations for residential ambient annual average (RAA) PNC and LN-transformed TAA-PNC with the biomarkers.

To examine the shape of the exposure-response functions, we produced generalized additive models (GAMs) in R version 3.1 with locally-weighted scatterplot smoothing (LOESS) (R, Vienna, Austria; Trevor, 2013). Separate GAMs were produced with adjustment for CVD risk factors and for those factors plus race/ethnicity.

3. Results

The majority of the study population was female, above the age of 60 years, overweight or obese, current or former smokers, and born outside of the US (Table 1). Non-Hispanic white and East Asian participants constituted 42% and 40% of the population, respectively. East Asians were concentrated in the Chinatown and Malden study areas.

3.1. Biomarker concentrations by population characteristics

Differences in median blood biomarker concentrations by population characteristics are shown in Table 2. All four biomarkers were higher for participants who were older, a current or former smoker, born in the US, or using statin or diabetes medications. Biomarker levels were also higher in participants who were obese (25–29.9 kg/m^2) and overweight (25–29.9 kg/m^2). East Asian participants had lower median levels of all biomarkers than white non-Hispanics and the other race/ethnicity category. Sex was associated with a minor difference for IL-6, but not for any other biomarker.

3.2. TAA-PNC by population characteristics

There were differences in annual average TAA-PNC exposure by study area (Table 3 and Fig. 1). Chinatown participants had the highest median (28,000 particles/cm^3) and maximum (35,000 particles/cm^3) annual average exposures, while Malden had the lowest median (10,000 particles/cm^3) and minimum (9000 particles/cm^3) annual average exposures. Somerville participants experienced an exposure gradient based on proximity to Interstate-93 (median near highway annual average = 24.000 particles/cm^3; median urban background annual average = 18.000 particles/cm^3). Dorchester and South Boston participants had the lowest median near highway annual average TAA-PNC (18,000 particles/cm^3) out of the three near-highway neighborhoods, with an urban background median annual average of 13,000 particles/cm^3. Annual average TAA-PNC was higher among participants identifying as East Asian or born outside the US compared to those identifying as white non-Hispanics or born in the US. This is consistent with the preponderance of the East Asian population residing in Chinatown. Nevertheless, the range of TAA-PNC exposures for East Asians overlapped substantially with exposures for the rest of the study population. Additionally, median annual average TAA-PNC decreased with increasing educational attainment and was lowest among obese individuals (Table 3).

3.3. Association of TAA-PNC and biomarkers

In univariate analysis of the full population, there was almost no association between TAA-PNC and the inflammatory markers (Table 4). Bivariate analysis showed that adjusting for BMI, race/ethnicity, nativity and smoking status changed the effect estimate between TAA-PNC and all the biomarkers by >10%. Sex had a small effect on the relationship between TAA-PNC and IL-6, but not the other biomarkers. The descriptive statistics for biomarkers and TAA-PNC for racial and ethnic subpopulations (Tables 2 and 3) are consistent with the possibility of negative confounding, with unadjusted associations resulting in essentially null associations (Table 4). Consistent with negative confounding given patterns in Table 3, multivariable adjustment for age, sex, BMI, smoking status and education led to positive associations of TAA-PNC with

Table 4
Comparison of regression models for association between an interquartile-range change in time-activity adjusted annual average particle number concentration (IQR = 10.000 particles/cm^3) and biomarkers of systemic inflammation (hsCRP, IL-6 and TNFRII) and coagulation (fibrinogen).

Model	hsCRP	IL-6	TNFRII	Fibrinogen
	% change (95% CI)	% change (95% CI)	% change (95% CI)	% change (95% CI)
Unadjusted	−8.0% (−23.3%, 11.7%)	−2.1% (−12.9%, 10.2%)	−0.05% (−6.1%, 5.4%)	−3.3% (−7.0%, 0.4%)
Adjusted[a]	9.8% (−8.3%, 31.4%)	5.8% (−5.6%, 18.5%)	3.6% (−1.9%, 9.4%)	−1.9% (−5.5%, 1.6%)
Adjusted[b]	14.0% (−4.6%, 36.2%)	8.9% (−2.6%, 21.8%)	5.1% (−0.4%, 10.9%)	−1.9% (−5.5%, 1.6%)
Adjusted[c]	14.8% (−4.1%, 37.4%)	8.1% (−3.6%, 21.2%)	4.6% (−1.0%, 10.5%)	−2.1% (−5.7%, 1.5%)

[a] Adjusted for age, sex, continuous BMI, smoking status and education.
[b] Adjusted for age, sex, continuous BMI, smoking status, education and race/ethnicity.
[c] Adjusted for age, sex, continuous BMI, smoking status, education and nativity.

Table 5
Comparison of regression models for association between an interquartile-range change in time-activity adjusted annual average particle number concentration (IQR = 10.000 particles/cm^3) and biomarkers of systemic inflammation (hsCRP, IL-6 and TNFRII) and coagulation (fibrinogen) stratified into white non-Hispanic and East Asian participants.

Model	hsCRP	IL-6	TNFRII	Fibrinogen
	% change (95% CI)	% change (95% CI)	% change (95% CI)	% change (95% CI)
White non-Hispanic				
Unadjusted	36.3% (−0.9%, 73.5%)	28.7% (4.4%, 53.0%)	15.5% (7.3%, 7.8%)	2.3% (−5.6%, 10.2%)
Adjusted[a]	32.7% (3.7%, 67.2%)	22.6% (−0.2%, 45.5%)	16.8% (5.8%, 27.7%)	−0.02% (−0.7%, 0.7%)
East Asian				
Unadjusted	9.7% (−13.5%, 32.9%)	5.0% (−9.9%, 19.7%)	−0.3% (−7.9%, 1.3%)	−1.8% (−6.4%, −2.7%)
Adjusted[a]	6.1% (−18.3%, 31.0%)	2.6% (−12.2%, 17.3%)	0.1% (−1.2%, 1.4%)	−0.06% (−5.4%, 4.2%)

[a] Adjusted for age, sex, continuous BMI, smoking status and education.

hsCRP, IL-6 and TNFRII (adjustment a, Table 4). Separate adjustment by race/ethnicity (adjustment b, Table 4) and nativity (adjustment c, Table 4) increased the TAA-PNC effect estimates and strength of association for hsCRP, IL-6 and TNFRII, with the largest effect on hsCRP and IL-6. None of the associations achieved traditional thresholds for significance, but all had positive central estimates and some approached significance.

Table 5 shows results with the population stratified into white non-Hispanics and East Asians. In adjusted models, TAA-PNC was positively associated with IL-6 and significantly associated with hsCRP and TNFRII among white non-Hispanic participants. Effect estimates were similar in unadjusted and adjusted models. In adjusted models, East Asian participants had much smaller (and non-significant) associations between TAA-PNC and all three biomarkers of inflammation.

TAA-PNC was negatively associated with fibrinogen in unadjusted and adjusted analysis (Table 4). In adjusted models, stratification by race/ethnicity also resulted in little associations in non-Hispanic white participants. East Asians had a negative association that was attenuated following adjustment (Table 5).

3.4. Additional analyses

Statin and diabetes medication (insulin/oral hypoglycemic) use and season of blood draw were not significant independent predictors. Their inclusion modestly increased the effect estimates for the association between TAA-PNC and biomarkers of inflammation, but did not meaningfully change the relationships (Supplemental Table 1). BMI as a categorical term and as a quadratic term in place of linear BMI were also run in separate models and their inclusion did not meaningfully change the relationship between TAA-PNC and biomarkers. In a separate model we replaced TAA-PNC with the RAA-PNC which lowered effect estimates for hsCRP and TNFRII, but increased the effect estimate for IL-6.

Substituting personal income for educational attainment to account for socioeconomic status did not meaningfully change effect estimates of associations for biomarkers of inflammation or fibrinogen. Neighborhood was not a significant predictor for hsCRP, IL-6 or fibrinogen, but adjusting for neighborhood reduced the association between TAA-PNC and TNFRII to essentially null. Although our study was underpowered to fully explore interactions with TAA-PNC, we conducted a series of stratified analyses to further evaluate differences. In stratified analyses, associations differed by sex (IL-6, TNFRII and fibrinogen), age (hsCRP, IL-6), smoking (hsCRP, TNFRII), BMI (hsCRP, TNFRII), born in the US (IL-6, TNFRII), statin medication use (IL-6, TNFRII), and diabetes medication use (hsCRP, IL-6). Effects were generally greater in less healthy subpopulations. Log transformed TAA-PNC was examined and similar results were observed as for the non-transformed TAA-PNC (Supplemental Tables 3 and 4).

GAMs were built to examine the shape of the exposure-response curves. In unadjusted models, the curve for hsCRP was U-shaped, explaining in part the null findings in Table 3. However, adjusting for CVD risk factors and race/ethnicity in particular increased the slope at higher TAA-PNC levels, consistent with our stratified results by race/ethnicity and reinforcing the interpretability of our fully adjusted models (Fig. 2). For IL-6 and TNFRII, adjustment for CVD risk factors and race/ethnicity also increased the exposure-response function at higher concentrations. Fibrinogen had a negative exposure-response curve in the unadjusted and adjusted GAMs.

4. Discussion

We used exposure models with high spatial-temporal resolution joined with individual time-activity patterns and found positive non-significant associations between annual average UFP exposures and multiple biomarkers of inflammation (hsCRP, IL-6 and TNFRII). We also found a negative non-significant association with fibrinogen. Stratification by race/ethnicity showed that TAA-PNC had larger effect estimates and was significantly associated with hsCRP and TNFRII in white non-Hispanic, but not East Asian participants. The association with systematic inflammatory markers is consistent with either chronic induction of pulmonary inflammation leading to a secondary systemic inflammation response or a primary systemic inflammatory response through particle translocation into the circulatory system. Both of these are expected to lead to cytokine responses and production of proteins such as hsCRP, IL-6 and TNFRII (Araujo et al., 2008; Rückerl et al., 2011; Simkhovich et al., 2008). Our findings are also consistent with studies that found associations between short-term PNC exposure and increases in hsCRP, IL-6 and TNFRII (Delfino et al., 2008; Hertel et al., 2010; Fuller et al., 2014).

Our analysis adds to the small, but growing evidence for a role of long-term exposure to UFP in adverse cardiovascular health impacts. Our significant results for non-Hispanic white populations are consistent with findings from other recent studies evaluating cardiovascular effects or inflammatory markers among predominantly non-Hispanic white populations (Ostro et al., 2015; Viehmann et al., 2015).

We saw limited evidence of a negative association with fibrinogen, although associations were essentially null, especially in adjusted models stratifying by race/ethnicity. Fibrinogen is an acute-phase protein important to the coagulation cascade, but studies of its association with TRAPs are inconclusive. Studies of short-term exposure to particulate matter have found positive associations with fibrinogen (Ghio et al., 2003; Rückerl et al., 2007), null associations (Pope et al., 2004; Samet et al., 2009), and a negative association (Seaton et al., 1999). The lack of a positive association between TAA-PNC and fibrinogen in our analysis could be due to PNC having a different mechanism of action on coagulation compared to inflammation, although the two pathways are also interconnected (Levi et al., 2004). To better understand the mechanistic effects of PNC on coagulation, future studies could include analysis of biomarkers at various stages of the coagulation pathway such as plasmin, von Willebrand factor, and *D*-dimer, markers that have been more consistently associated with acute TRAP exposure (Riediker et al., 2004; Yue et al., 2007).

Our study differs from previous research on long-term residential UFP health impacts in that we used a more finely resolved spatial UFP model (20 m, compared to 1–4 km) that leveraged extensive ambient

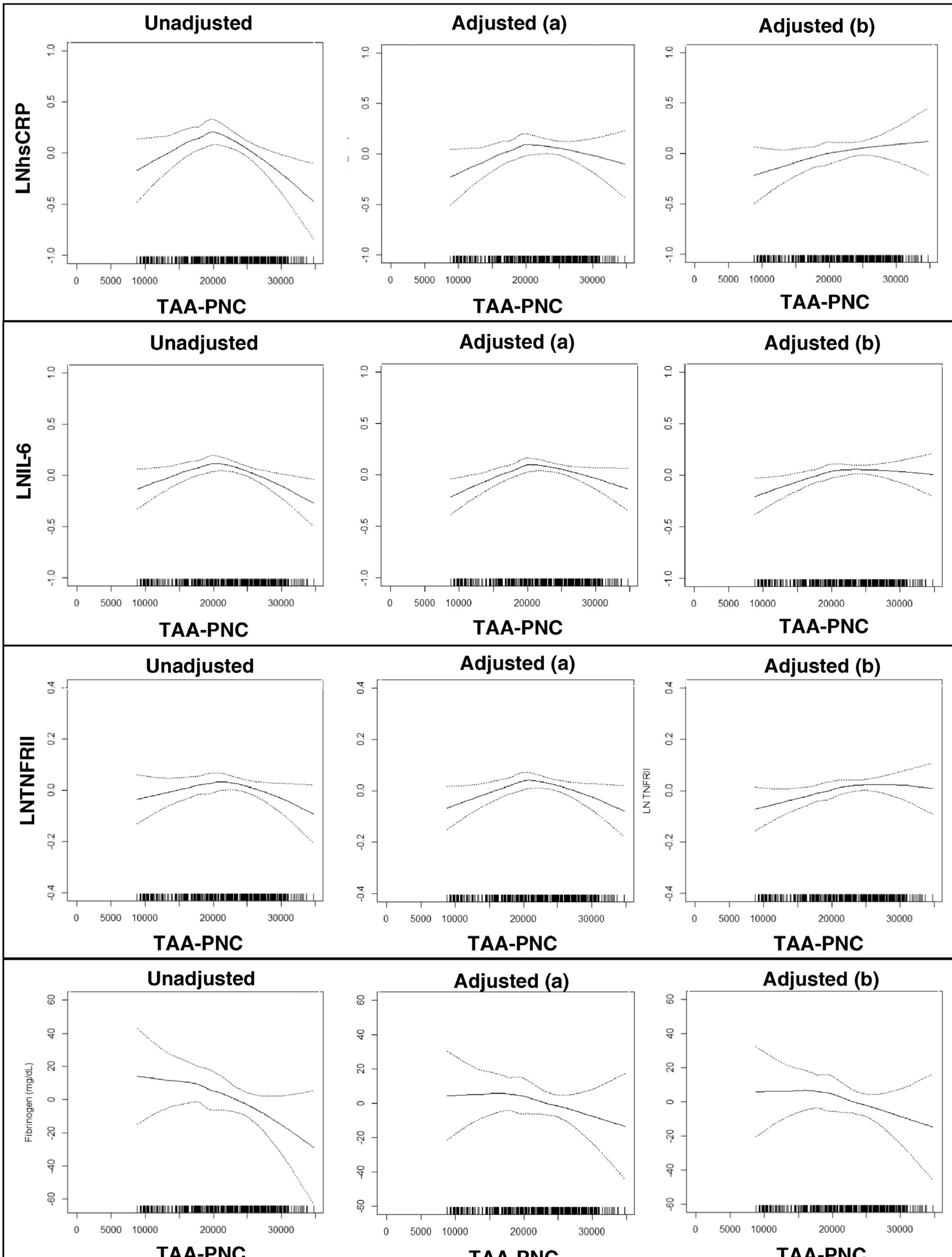


Fig. 2. Comparison of GAM with a LOESS TAA-PNC term for association with the biomarkers of systemic inflammation by additionally adjusting for race. Adjusted (a) for age, gender, BMI, smoking status and education. Adjusted (b) for age, gender, BMI, smoking status, education and race.

monitoring, combined with time-activity adjustment of exposures that may reduce exposure misclassification (Lane et al., 2015). We also had a diverse racial/ethnic study population, with a high percentage of East Asian participants (40%) who were not born in the US and who also tended to be the most highly exposed subpopulation. Interestingly, in our race/ethnicity stratified models for hsCRP, IL-6 and TNFRII (Table 5), we found white non-Hispanics had larger (and statistically significant) effect estimates compared to the East Asian participants. Previous studies have found differences in biomarkers of systemic inflammation by race/ethnicity (Corlin et al., 2014; Khera et al., 2005). Studies reported lower hsCRP concentrations in East Asian participants residing in the US compared to white participants (Albert et al., 2004; Kelley-Hedgepeth et al., 2008; Lakoski et al., 2006). Studies in Asia have also reported relatively low CRP levels (Ye et al., 2007). Similarly, in a prior analysis of the CAFEH study population, we found that East Asian participants had lower IL-6 and TNFRII as well as lower hsCRP concentrations compared to non-Hispanic white participants (Corlin et al., 2014). Studies have found that Chinese Americans have less CVD risk and lower inflammatory markers than other races/ethnicities (Palaniappan et al., 2004; Lakoski et al., 2006). A recent study found Chinese Americans had lower carotid intima-media thickness response to $PM_{2.5}$ exposures, irrespective of receiving higher exposures than white non-Hispanic and Latino race/ethnicities (Jones et al., 2015). It is possible that differences in systemic inflammatory markers by race/ethnicity lead to different response functions with ambient air pollutants. However, the mechanism remains unclear and could be related to differences in genetics, physical activity, nutrition and/or social cohesion.

We found differences in effect estimates by sex on the associations between TAA-PNC and TNFRII and fibrinogen. This agrees with previous literature of notable albeit non-uniform effect modification by sex on the relation of air pollution with inflammatory response (Clougherty, 2010). The lower association with TNFRII in women may reflect genetic differences that result in lower expression of TNFRII in female hearts compared to male hearts (Ramani et al., 2004). Differences in the relationship for fibrinogen may relate to differences in behaviors or activity patterns between men and women rather than genetic factors (Carter et al., 1997).

To help interpret our regression models, we can estimate the influence of both PNC and BMI on hsCRP in our study population. In linear multivariable models that adjusted for age, sex, BMI, smoking status and education, we found that a 10,000 particles/cm^3 change in TAA-PNC exposure was associated with a 14.0% change in hsCRP. Comparatively, a 1.8 kg/m^2 change in BMI would also be associated with a 14.0% change in hsCRP. To make this comparison more tangible, moving from exposure levels consistent with the urban background to exposure levels consistent with the near-highway neighborhood in Somerville (a change in median exposure from 18,000 to 24,000 particles/cm^3) would be associated with a change in mean hsCRP levels from 0.97 mg/L to 1.05 mg/L. In contrast, moving from a normal weight BMI of 22 kg/m^2 to an overweight BMI of 27 kg/m^2 equates to a change in mean hsCRP levels from 0.68 mg/L to 1.04 mg/L. Of note, our BMI effect estimates are slightly higher than those observed in another multi-ethnic study (Festa et al., 2001). Given that approximately 30 million Americans live within 300 m of a major roadway (US EPA, 2015), there could be significant public health implications from these small changes in hsCRP.

4.1. Strengths and limitations

Multiple aspects of the CAFEH study were strengthened by our collaborations with community partners. The initial impetus of the study originated as a request from the Somerville Transportation Equity Partnership. Community partners contributed to all aspects of the study, including overall study design, by providing expert local knowledge that helped us define study boundaries, design effective recruitment strategies, and improve geocoding by obtaining apartment floor plans through housing management. Community partners also collaborated with researchers on hiring and training of field staff, translation of documents, interpretation of results, writing of manuscripts and dissemination of findings.

The PNC regression model used here was developed from a dense mobile monitoring campaign that encompassed the residences of participants. This allowed us to model and estimate local hourly ambient PNC values. These values were subsequently adjusted for time-activity to produce individual TAA-PNC estimates, which may reduce exposure misclassification (Lane et al., 2015). TAA adjustment increased effect estimates in our analysis (Supplemental Table 4). Nevertheless, residual exposure misclassification likely remains due to the challenges in capturing all spatiotemporal contributors in a PNC regression model. Additional error may be due to inaccuracies in time-activity adjustment. However, our time activity adjustment was based on survey data that was highly reproducible (Lane et al., 2013), although it only covered five micro-environments.

CAFEH is a cross-sectional study; therefore we cannot determine the temporal nature of the exposure–response relationship or make causal inferences. In addition, our modest sample had considerable heterogeneity, especially for race/ethnicity, which complicated efforts to control for confounding. Our sample size also implies caution in interpreting the shape of the exposure-response functions in our GAMs, given substantially wider confidence intervals at the tails. Restricting the population to only random participants, however, did not substantially change our findings, increasing confidence generalizability.

PNC is correlated with other TRAPs such as road dust, other traffic-related coarse particles, particle-bound polycyclic aromatic hydrocarbons (pPAH), NOx, and CO (Johansson et al., 2007; Patton et al., 2014b), as well as traffic-related noise (Can et al., 2015). Exposures to these pollutants might confound or interact with PNC and each other (Karner et al., 2010; US EPA, 2015) and could explain portions of our observed associations. However, the mechanism by which gaseous pollutants like NOx influence cardiovascular health is less clear than for PNC. Further, $PM_{2.5}$ was shown to have little spatial variability throughout our study areas (Patton et al., 2014b).

5. Conclusions

We identified positive but non-significant associations of long-term TAA-PNC exposure with hsCRP, IL-6 and TNFRII, but not with fibrinogen, after adjusting for traditional CVD risk factors, including BMI and smoking status. Stratification by race/ethnicity resulted in stronger associations between TAA-PNC and biomarkers of inflammation among white non-Hispanic compared to East Asian participants. Adjustment by race/ethnicity also produced more interpretable exposure-response functions. Our findings reinforce the importance of studying near-highway PNC exposures and of examining differences in exposure patterns and associations among racial/ethnic sub-populations. Longitudinal cohort studies and multipollutant models will be needed to strengthen causal interpretation.

Acknowledgments

We are grateful to the CAFEH Steering Committee including Baolian Kuang, Michelle Liang, Christina Hemphill Fuller, Edna Carrasco, M Barton Laws, and Mario Davila. We also acknowledge the great help from our community partners the Somerville Transportation Equity Partnership (STEP), the Committee for Boston Public Housing, the Chinese Progressive Association, and the Chinatown Resident Association. We thank our project manager Don Meglio and his field team—Kevin Stone, Marie Manis, Consuelo Perez, Marjorie Alexander, Maria Crispin, Reva Levin, Helene Sroat, Carmen Rodriguez, Migdalia Tracy, Sidia Escobar, Kim-Lien Le, Stephanie Saintil, Robert Baptiste, Joseph Penella, Lisa Ng, Vladimir Albin Jr., Janet Vo, Quynh Dam, Lin Yian, Betsey

Rodman, Marie Echevarria, and Barbara Anderson—for their dedication and hard work. We received analytical advice from David Arond, Mkaya M Mwamburi and Laura Corlin; as well as database support of Deena Wang. Luz Padró-Martínez, Jeffrey Trull, Eric Wilburn, Piers MacNaughton, Tim McAuley, Samantha Weaver, Caitlin Collins, and Jessica Perkins contributed to the mobile monitoring and PNC modeling effort. Funding for CAFEH was provided by the National Institute of Environmental Health Sciences (NIEHS) (Grant No. ES015462). Support for CAFEH was also provided by the Jonathan M. Tisch College of Citizenship and Public Service and the Tisch College Community Research Center at Tufts. Predoctoral support for KJL and APP was provided by the Environmental Protection Agency (EPA) Science to Achieve Results graduate fellowship program (Grant Nos.: FP-917349 and FP-917203). This manuscript has not been formally reviewed by the EPA. The views expressed in this manuscript are solely those of the authors, and EPA does not endorse any products or commercial services mentioned in this manuscript. MKS was supported by a JPB Environmental Health Fellowship award granted by The JPB Foundation and managed by the Harvard T.H. Chan School of Public Health.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.envint.2016.03.013.

References

Albert, M.A., Glynn, R.J., Buring, J., Ridker, P.M., 2004. *C*-reactive protein levels among women of various ethnic groups living in the United States (from the Women's Health Study). J. Am. Coll. Cardiol. 93 (10), 1238–1242.

Araujo, J.A., Nel, A.E., 2009. Particulate matter and atherosclerosis: role of particle size, composition and oxidative stress. Part. Fibre Toxicol. 6, 24.

Araujo, J.A., Barajas, B., Kleinman, M., Wang, X., Bennett, B.J., Gong, K.W., et al., 2008. Ambient particulate pollutants in the ultrafine range promote early atherosclerosis and systemic oxidative stress. Circ. Res. 102 (5), 589–596.

Brugge, D., Durant, J.L., Rioux, C., 2007. Near-highway pollutants in motor vehicle exhaust: a review of epidemiologic evidence of cardiac and pulmonary health risks. Environ. Health 6, 23.

Brugge, D., Lane, K., Padró-Martínez, L.T., Stewart, A., Hoesterey, K., Weiss, D., et al., 2013. Highway proximity associated with cardiovascular disease risk: the influence of individual-level confounders and exposure misclassification. Environ. Health 12 (1), 84.

Buonanno, G., Stabile, L., Morawska, L., 2014. Personal exposure to ultrafine particles: the influence of time-activity patterns. Sci. Total Environ. 468–469, 903–907.

Can, A., Rademaker, M., Van Renterghem, T., Mishra, V., Van Poppel, M., Touhafi, A., Theunis, J., De Baets, B., Botteldooren, D., 2015. Correlation analysis of noise and ultrafine particle counts in a street canyon. Sci. Total Environ. 409 (3), 564–572.

Carter, A.M., Catto, A.J., Bamford, J.M., Grant, P.J., 1997. Gender-specific associations of the fibrinogen B beta 448 polymorphism, fibrinogen levels, and acute cerebrovascular disease. Arterioscler. Thromb. Vasc. Biol. 17 (3), 589–594.

Clougherty, J.E., 2010. A Growing Role for Gender Analysis in Air Pollution Epidemiology. Environ. Health Perspect. 118, 167–176.

Corlin, L., Woodin, M., Thanikachalam, M., Lowe, L., Brugge, D., 2014. Evidence for the healthy immigrant effect in older Chinese immigrants: a cross-sectional study. BMC Public Health 14 (1), 603.

Delfino, R.J., Staimer, N., Tjoa, T., Polidori, A., Arhami, M., Gillen, D.L., et al., 2008. Circulating biomarkers of inflammation, antioxidant activity, and platelet activation are associated with primary combustion aerosols in subjects with coronary artery disease. Environ. Health Perspect. 116 (7), 898–906.

Devlin, R.B., Smith, C.B., Schmitt, M.T., Rappold, A.G., Hinderliter, A., Graff, D., et al., 2014. Controlled exposure of humans with metabolic syndrome to concentrated ultrafine ambient particulate matter causes cardiovascular effects. Toxicol. Sci. 140 (1), 61–72.

Festa, A., D'Agostino, R., Williams, K., Karter, A.J., Mayer-Davis, E.J., Tracy, R.P., et al., 2001. The relation of body fat mass and distribution to markers of chronic inflammation. Int. J. Obes. 25, 1407–1415.

Fuller, C.H., Brugge, D., Williams, P.L., Mittleman, M.A., Lane, K., Durant, J.L., et al., 2013. Indoor and outdoor measurements of particle number concentration in near-highway homes. J.Expo. Sci. Environ. Epidemiol. 23 (5), 506–512.

Fuller, C.H., Patton, A.P., Lane, K., Laws, M.B., Marden, A., Carrasco, E., et al., 2014. A community participatory study of cardiovascular health and exposure to near-highway air pollution: study design and methods. Rev. Environ. Health 28 (1), 21–35.

Fuller, C.H., Williams, P.L., Mittleman, M.A., Patton, A.P., Spengler, J.D., Brugge, D., 2015. Response of biomarkers of inflammation and coagulation to short-term changes in central site, local, and predicted particle number concentrations. Ann. Epidemiol. 25 (7), 505–511.

Gan, W.Q., Allen, R.W., Brauer, M., Davies, H.W., Mancini, G.B., Lear, S.A., 2014. Long-term exposure to traffic-related air pollution and progression of carotid artery atherosclerosis: a prospective cohort study. BMJ Open 4 (4), e004743.

Gan, W.Q., Koehoorn, M., Davies, H.W., 2011. Long-term exposure to traffic-related air pollution and the risk of coronary heart disease hospitalization and mortality. Environ. Health Perspect. 119, 501–507.

Ghio, A.J., Hall, A., Bassett, M.A., Cascio, W.E., Devlin, R.B., 2003. Exposure to concentrated ambient air particles alters hematologic indices in humans. Inhal. Toxicol. 15 (14), 1465–1478.

Gu, J., Kraus, U., Schneider, A., Hampel, R., Pitz, M., Breitner, S., Wolf, K., Hänninen, O., Peters, A., Cyrys, J., 2015. Personal day-time exposure to ultrafine particles in different microenvironments. Int. J. Hyg. Environ. Health 218 (2), 188–195. http://dx.doi.org/10.1016/j.ijheh.2014.10.002.

HEI Review Panel on Ultrafine Particles, 2013. Understanding the Health Effects of Ambient Ultrafine Particles. HEI Perspectives 3. Health Effects Institute, Boston, MA.

Hertel, S., Viehmann, A., Moebus, S., Mann, K., Bröcker-Preuss, M., Möhlenkamp, S., Nonnemacher, M., Erbel, R., Jakobs, H., Memmesheimer, M., Jöckel, K.H., Hoffmann, B., 2010. Influence of short-term exposure to ultrafine and fine particles on systemic inflammation. Eur. J. Epidemiol. 25 (8), 581–592.

Hoffmann, B., Moebus, S., Dragano, N., Stang, A., Möhlenkamp, S., Schmermund, A., Memmesheirmer, M., Brocker-Preuss, M., Mann, K., Erbel, R., Jockel, K., 2009. Chronic residential exposure to particulate matter air pollution and systemic inflammatory markers. Environ. Health Perspect. 117, 1302–1308.

Johansson, C, Norman, M, Gidhagen, L, 2007. Spatial & temporal variations of PM10 and particle number concentrations in urban air. Environ. Monit. Assess. 127 (1–3), 477–487.

Jones, M.R., Diez-Roux, A.V., O'Neill, M.S., Guallar, E., Sharrett, A.R., Post, W., Kaufman, J.D., Navas-Acien, A., 2015. Ambient air pollution and racial/ethnic differences in carotid intima-media thickness in the multi-ethnic study of atherosclerosis (MESA). J. Epidemiol. Community Health 69 (12), 1191–1198.

Karner, A.A., Eisinger, D.S., Niemeier, D.A., 2010. Near-roadway air quality: synthesizing the findings from real-world data. Environ. Sci. Technol. 44, 5334–5344.

Kelley-Hedgepeth, A., Lloyd-Jones, D.M., Colvin, A., Matthews, K.A., Johnston, J., Sowers, M.R., et al., 2008. Ethnic differences in *C*-reactive protein concentrations. Clin. Chem. 54 (6), 1027–1037.

Khera, A., McGuire, D.K., Murphy, S.A., Stanek, H.G., Das, S.R., Vongpatanasin, W., et al., 2005. Race and gender differences in *C*-reactive protein levels. J. Am. Coll. Cardiol. 46 (3), 464–469.

Lane, K.J., Kangsen Scammell, M., Levy, J.I., Fuller, C.H., Parambi, R., Zamore, W., et al., 2013. Positional error and time-activity patterns in near-highway proximity studies: an exposure misclassification analysis. Environ. Health 12 (1), 75.

Lane, K.J., Levy, J.I., Kangsen Scammell, M., Patton, A.P., Durant, J.L., Zamore, W., et al., 2015. The influence of time-activity adjustment on exposure estimates for traffic-related ultrafine particles. J. Expo. Sci. Environ. Epidemiol. 25 (5), 506–516.

Lanki, T., Hampel, R., Tiittanen, P., Andrich, S., Beelen, R., Brunekreef, B., et al., 2015. Air pollution from road traffic and systemic inflammation in adults: a cross-sectional analysis in the European ESCAPE Project. Environ. Health Perspect. 123 (8), 785–791.

Lakoski, S.G., Cushman, M., Criqui, M., Rundek, T., Blumenthal, R.S., D'Agostino, R.B., et al., 2006. Gender and *C*-reactive protein: data from the multiethnic study of atherosclerosis (MESA) cohort. Am. Heart J. 152 (3), 593–598.

Levi, M., Poll, T.V., Büller, H.R., 2004. Bidirectional relation between inflammation and coagulation. Circulation 109, 2698–2704.

McDade, T.W., Lindau, S.T., Wroblewski, K., 2011. Predictors of *C*-reactive protein in the national social life, health, and aging project. J. Gerontol. B Psychol. Sci. Soc. Sci. 66 (1), 129–136.

Nemmar, A., Hoet, P.H., Vanquickenborne, B., Dinsdale, D., Thomeer, M., Hoylaerts, M.F., 2002. Passage of inhaled particles into the blood circulation in humans. Circulation 105, 411–414.

Ostro, B., Hu, J., Goldberg, D., Reynolds, P., Hertz, A., Bernstein, L., Kleeman, M.J., 2015. Associations of mortality with long-term exposures to fine and ultrafine particles, species and sources: results from the California teachers study cohort. Environ. Health Perspect. 123 (6), 549–556.

Padró-Martínez, L.T., Patton, A.P., Trull, J.B., Zamore, W., Brugge, D., Durant, J.L., 2012. Mobile monitoring of particle number concentration and other traffic-related air pollutants in a near-highway neighborhood over the course of a year. Atmos. Environ. 61, 253–264.

Palaniappan, L., Wang, Y., Fortmann, S.P., 2004. Coronary heart disease mortality for six ethnic groups in California, 1990–2000. Ann. Epidemiol. 14, 499–506.

Patton, A.P., Collins, C., Naumova, E.N., Zamore, W., Brugge, D., Durant, J.L., 2014a. An hourly regression model for ultrafine particles in a near-highway urban area. Environ. Sci. Technol. 48 (6), 3272–3280.

Patton, A.P., Perkins, J., Zamore, W., Levy, J.I., Brugge, D., Durant, J.L., 2014b. Spatial and temporal differences in traffic-related air pollution in three urban neighborhoods near an interstate highway. Atmos. Environ. 99, 309–321.

Patton, A.P., Zamore, W., Naumova, E.N., Levy, J.I., Brugge, D., Durant, J.L., 2015. Transferability and generalizability of regression models of ultrafine particles in urban neighborhoods in the Boston area. Environ. Sci. Technol. 49 (10), 6051–6060.

Pope, C.A., Hansen, M.L., Long, R.W., Nielsen, K.R., Eatough, N.L., Wilson, W.E., et al., 2004. Ambient particulate air pollution, heart rate variability, and blood markers of inflammation in a panel of elderly subjects. Environ. Health Perspect. 112 (3), 339–345.

Ramani, R., Mathier, M., Wang, P., Gibson, G., Tögel, S., Dawson, J., Bauer, A., Alber, S., Watkins, S.C., McTiernan, C.F., Feldman, A.M., 2004 Sept.t. Inhibition of tumor necrosis factor receptor-1-mediated pathways has beneficial effects in a murine model of postischemic remodeling. Am. J. Physiol. Heart Circ. Physiol. 287 (3), H1369–H1377.

Riediker, M., Cascio, W.E., Griggs, T.R., Herbst, M.C., Bromberg, P.A., Neas, L., et al., 2004. Particulate matter exposure in cars is associated with cardiovascular effects in healthy young men. Am. J. Respir. Crit. Care Med. 169, 934–940.

Rückerl, R., Greven, S., Ljungman, P., Aalto, P., Antoniades, C., Bellander, T., et al., 2007. Air pollution and inflammation (interleukin-6, C-reactive protein, fibrinogen) in myocardial infarction survivors. Environ. Health Perspect. 115 (7), 1072–1080.

Rückerl, R., Hampel, R., Breitner, S., Cyrys, J., Kraus, U., Carter, J., et al., 2014. Associations between ambient air pollution and blood markers of inflammation and coagulation/fibrinolysis in susceptible populations. Environ. Int. 70, 32–49.

Rückerl, R., Schneider, A., Breitner, S., Cyrys, J., Peters, A., 2011. Health effects of particulate air pollution: a review of epidemiological evidence. Inhal. Toxicol. 23, 555–592.

Samet, J.M., Rappold, A., Graff, D., Cascio, W.E., Berntsen, J.H., Huang, Y.C., et al., 2009. Concentrated ambient ultrafine particle exposure induces cardiac changes in young healthy volunteers. Am. J. Respir. Crit. Care Med. 179 (11), 1034–1042.

Seaton, A., Soutar, A., Crawford, V., Elton, R., McNerlan, S., Cherrie, J., et al., 1999. Particulate air pollution and the blood. Thorax 54 (11), 1027–1032.

Simkhovich, B.Z., Kleinman, M.T., Kloner, R.A., 2008. Air pollution and cardiovascular injury epidemiology, toxicology, and mechanisms. J. Am. Coll. Cardiol. 52 (9), 719–726.

Sioutas, C., Delfino, R.J., Singh, M., 2005. Exposure assessment for atmospheric ultrafine particles (UFPs) and implications in epidemiologic research. Environ. Health Perspect. 113 (8), 947–955.

Trevor, H., 2013. Generalized additive models. R Package version 1 (09), 1.

U.S. Environmental Protection Agency Office of Transportation and Air Quality (OTAQ). 2015. Near roadway air pollution and health. Washington, D.C. http://www.epa.gov/otaq/nearroadway.htm [Accessed on June 8th, 2015].

Viehmann, A., Hertel, S., Fuks, K., Eisele, L., Moebus, S., Möhlenkamp, S., Nonnemacher, M., Jakobs, H., Erbel, R., KH, Jöckel, Hoffmann, B., Heinz Nixdorf Recall Investigator Group, 2015. Long-term residential exposure to urban air pollution, and repeated measures of systemic blood markers of inflammation and coagulation. Occup. Environ. Med. 72 (9), 656–663.

Williams, L.A., Ulrich, C.M., Larson, T., Wener, M.H., Wood, B., Campbell, P., Potter, J., McTiernan, A., De Roos, A., 2009. Proximity to traffic, inflammation, and immune function among women in the Seattle, Washington, area. Environ. Health Perspect. 117, 374–378.

Wu, C.D., MacNaughton, P., Melly, S., Lane, K., Adamkiewicz, G., Durant, J.L., et al., 2014. Mapping the vertical distribution of population and particulate air pollution in a near-highway urban neighborhood: implications for exposure assessment. J. Expo. Sci. Environ. Epidemiol. 24 (3), 297–304.

Ye, X., Yu, Z., Li, H., Franco, O.H., Liu, Y., Lin, X., 2007. Distributions of C-reactive protein and its association with metabolic syndrome in middle-aged and older Chinese people. J. Am. Coll. Cardiol. 49 (17), 1798–1805.

Yue, W., Schneider, A., Stolzel, M., Ruckerl, R., Cyrys, J., Pan, X., et al., 2007. Ambient source-specific particles are associated with prolonged repolarization and increased levels of inflammation in male coronary artery disease patients. Mutat. Res. 621, 50–60.

Atmospheric Environment 99 (2014) 309–321

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Spatial and temporal differences in traffic-related air pollution in three urban neighborhoods near an interstate highway

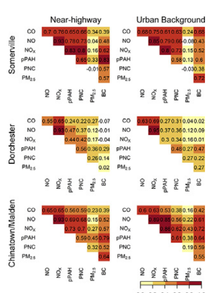
Allison P. Patton [a,*], Jessica Perkins [a], Wig Zamore [b], Jonathan I. Levy [c], Doug Brugge [d], John L. Durant [a]

[a] Civil and Environmental Engineering, Tufts University, 200 College Ave, Medford, MA 02155, USA
[b] Somerville Transportation Equity Partnership, Somerville, MA, USA
[c] Boston University School of Public Health, 715 Albany St, Boston, MA 02118, USA
[d] Public Health and Community Medicine, Tufts University, 136 Harrison Avenue, Boston, MA 02111, USA

HIGHLIGHTS

- We compared traffic-related air pollution in 3 Boston-area neighborhoods near I-93.
- Pollutant distance-decay gradients were different in each neighborhood.
- Pollutant correlations varied by neighborhood, season, and time of day.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 23 June 2014
Received in revised form
13 September 2014
Accepted 25 September 2014
Available online 28 September 2014

Keywords:
Near-highway
Distance-decay gradients
Mobile monitoring
Traffic-related air pollution
Metropolitan Boston (USA)

ABSTRACT

Relatively few studies have characterized differences in intra- and inter-neighborhood traffic-related air pollutant (TRAP) concentrations and distance-decay gradients in neighborhoods along an urban highway for the purposes of exposure assessment. The goal of this work was to determine the extent to which intra- and inter-neighborhood differences in TRAP concentrations can be explained by traffic and meteorology in three pairs of neighborhoods along Interstate 93 (I-93) in the metropolitan Boston area (USA). We measured distance-decay gradients of seven TRAPs (PNC, pPAH, NO, NO_X, BC, CO, $PM_{2.5}$) in near-highway (<400 m) and background areas (>1 km) in Somerville, Dorchester/South Boston, Chinatown and Malden to determine whether (1) spatial patterns in concentrations and inter-pollutant correlations differ between neighborhoods, and (2) variation within and between neighborhoods can be explained by traffic and meteorology. The neighborhoods ranged in area from 0.5 to 2.3 km^2. Mobile monitoring was performed over the course of one year in each pair of neighborhoods (one pair of neighborhoods per year in three successive years; 35–47 days of monitoring in each neighborhood). Pollutant levels generally increased with highway proximity, consistent with I-93 being a major source of TRAP; however, the slope and extent of the distance-decay gradients varied by neighborhood as well as by pollutant, season and time of day. Spearman correlations among pollutants differed between neighborhoods (e.g., $\rho = 0.35-0.80$ between PNC and NO_X and $\rho = 0.11-0.60$ between PNC and BC) and were generally lower in Dorchester/South Boston than in the other neighborhoods. We found that the generalizability of near-road gradients and near-highway/urban background contrasts was limited for

* Corresponding author. Present address: Environmental and Occupational Health Sciences Institute, Rutgers University, 170 Frelinghuysen Road, Piscataway, NJ 08854, USA.
E-mail addresses: patton@eohsi.rutgers.edu, allison.patton@alumni.tufts.edu (A.P. Patton).

http://dx.doi.org/10.1016/j.atmosenv.2014.09.072

near-highway neighborhoods in a metropolitan area with substantial local street traffic. Our findings illustrate the importance of measuring gradients of multiple pollutants under different ambient conditions in individual near-highway neighborhoods for health studies involving inter-neighborhood comparisons.

1. Introduction

Living near major roadways is associated with increased risks of cardiovascular and pulmonary disease (Gan et al., 2009; Hoek et al., 2013; McConnell et al., 2010). The possibility that exposure to traffic-related air pollution (TRAP) may play a role has motivated research to understand which, if any, of the many components of TRAP may be causative agents (Brugge et al., 2007; HEI, 2010).

Disentangling the effects of TRAP components in health studies requires an understanding of how pollutants are patterned in space and time, and the extent to which patterns differ by pollutant and across geographic settings. TRAP concentrations can vary significantly in both space and time near roadways (Karner et al., 2010; Levy et al., 2013). Sharp decreases in the concentration of many pollutants including elemental carbon (EC), black carbon (BC), carbon monoxide (CO), nitrogen oxides (NO_X), particle number (PNC), and volatile organic compounds have been measured within 150–650 m of the edges of highways and major roads (Durant et al., 2010; Karner et al., 2010; Padró-Martínez et al., 2012; Pattinson et al., 2014; Roorda-Knape et al., 1998). The most-pronounced gradients occur for more reactive pollutants with low background concentrations, such as NO and ultrafine particles (UFP; <100 nm in diameter), and the least-pronounced gradients occur for relatively inert pollutants with elevated background concentrations (e.g., fine particle mass) (Zhou and Levy, 2007). In urban areas, spatial characterization can be complicated by street canyons and roadside structures such as noise barriers, elevated or depressed roadways, and buffers of trees and shrubs (Hagler et al., 2012, 2010; Ning et al., 2010; Vardoulakis et al., 2003). Studies suggest that roadside structures tend to decrease near-road TRAP concentrations and increase on-road concentrations (Finn et al., 2010; Hagler et al., 2012; Ning et al., 2010; Steffens et al., 2014).

While previous efforts have focused on TRAP variation between cities (Eeftens et al., 2012; Fruin et al., 2014; Lebret et al., 2000) and within cities (Clougherty et al., 2008; Dons et al., 2013; Duvall et al., 2012; Jerrett et al., 2005; Levy et al., 2014), there are relatively few reports on the extent to which TRAP concentrations and spatial distributions measured in one near-highway neighborhood can be generalized to other neighborhoods along the same highway. Studies are needed that characterize TRAP variation at fine scales – e.g., <~5 km^2 neighborhoods – for the purpose of developing accurate estimates of TRAP exposures in urban populations. Because spatial distributions of TRAP are also affected by factors that vary by season and time of day (such as wind patterns, temperature, and emissions source strength) (Kassomenos et al., 2014; Levy et al., 2013), measurement campaigns aimed at characterizing spatial differences in near-highway TRAP in neighborhoods should be performed over time. One way to measure differences in TRAP distance-decay gradients and temporal trends near highways is to conduct mobile monitoring along a highway in a single urban area in different seasons and times of day.

The goal of our study was to characterize gradients of seven TRAPs (PNC, pPAH, NO, NO_X, BC, CO, $PM_{2.5}$) in three near-highway (<400 m) and three background (>1000 m from nearest interstate highway) urban neighborhoods in the metropolitan Boston area (Massachusetts, United States). Our specific objectives were to determine whether (1) spatial patterns in concentrations and inter-pollutant correlations differ between neighborhoods, and (2) variation within and between neighborhoods can be explained by traffic and meteorology. We hypothesized that for each study area TRAP concentrations would be higher near highways than in urban background areas, and that pollutant distance-decay gradients could be explained in terms of traffic and meteorology. In particular, we expected that gradients would be similar in neighborhoods with single highways compared to neighborhoods with multiple major roadways and tall buildings, and that TRAP concentrations and the composition of TRAP mixtures would change in response to temporally-variable forcings. This work was performed as part of the Community Assessment of Freeway Exposure and Health study (CAFEH), a community-based participatory research (CBPR) study of TRAP exposure and cardiovascular health risk (Fuller et al., 2013).

2. Material and methods

2.1. Study area descriptions

TRAP concentrations were measured in three demographically-matched pairs of near-highway (NH) and urban background (UB) neighborhoods in the Boston metropolitan area: Somerville (NH and UB), Dorchester/South Boston (NH and UB), Chinatown (NH) and Malden (UB; Fig. 1). Study areas were relatively small, ranging in size from 0.5 km^2 (Chinatown) to 2.3 km^2 (Somerville; Table 1). Near-highway neighborhoods were defined as being 0–400 m from the nearest edge of Interstate 93 (I-93), which carries an average daily traffic (ADT) load of 1.5×10^5 vehicles per day (vpd; Central Transportation Planning Staff, 2012). Diesel vehicles accounted for 3.8% of I-93 traffic and <5% of traffic on local roads (Callahan, 2012; McGahan et al., 2001).

Mobile monitoring in all three pairs of neighborhoods was conducted over the course of a year (Table 2; Fig. S1). Monitoring was conducted in Somerville (Fig. 1A and B) from September 2009 to August 2010. Somerville air pollution sources were dominated by major roadways, including I-93, state highways, and a collector road. Route-38 (Mystic Avenue, ADT = 30,000 vpd; Central Transportation Planning Staff, 2012), a four-lane state highway adjacent to I-93 in Somerville, was defined as part of the I-93 highway corridor. Monitoring was conducted in Dorchester and South Boston, herein referred to as "Dorchester" (Fig. 1C and D), from September 2010 to July 2011. In this area, I-93 runs parallel to railroad lines about 3 m–6 m below grade. Monitoring in Chinatown (Fig. 1E) and Malden (Fig. 1F) was performed between August 2011 and July 2012. Chinatown is located in downtown Boston and contains many major roadways and street canyons. The neighborhood is also near South Station, a regional transportation hub for trains and buses. Chinatown is flanked on its east side by I-93 and bisected east to west by I-90 (~90,000 vpd; Central Transportation Planning Staff, 2012). A residential neighborhood in Malden with similar demographics was selected as the background area to pair with Chinatown because all of Chinatown was <400 m from I-93. The Malden study area contains a diesel bus terminal and two commuter

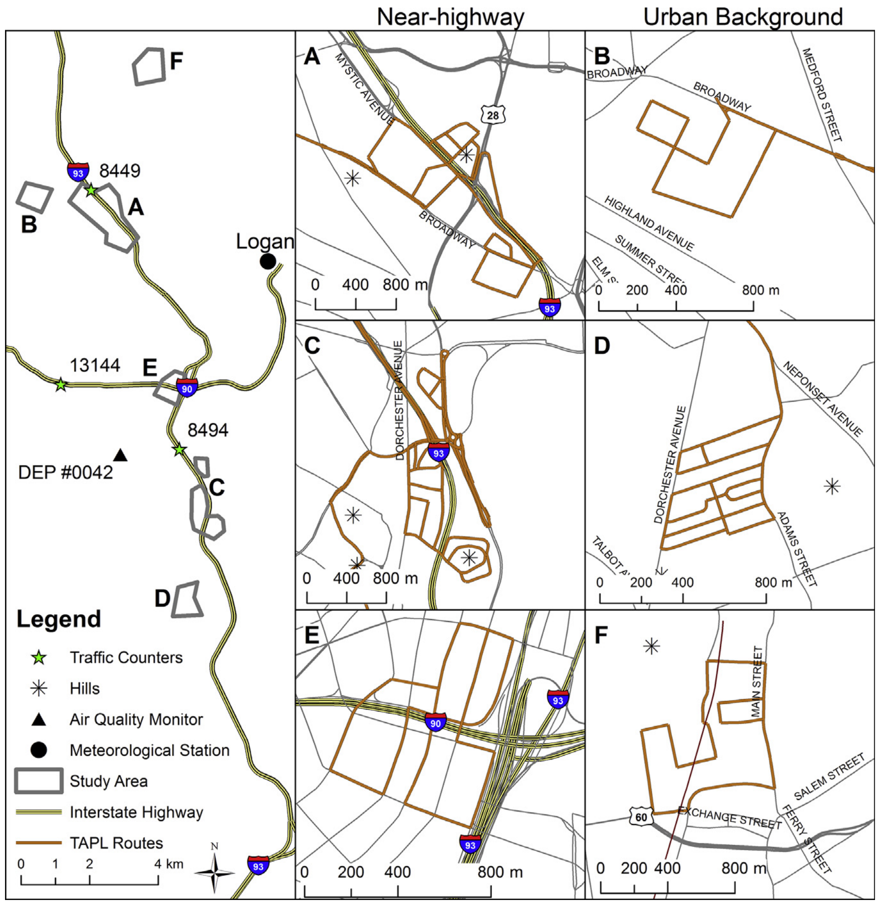


Fig. 1. Mobile monitoring areas and driving routes. Somerville near-highway (A) and urban background (B) were monitored from September 2009 through August 2010; Dorchester near-highway (C) and urban background (D) were monitored from September 2010 through August 2011; Chinatown (near-highway; E) and Malden (urban background; F) were monitored from August 2011 through July 2012. "DEP #0042" is a Boston EPA Speciation Trends Network site (ID: 25-025-0042). Road layers from MassGIS (2008a).

rail stations. More details on key features of each study area are available in Table 1 and Supporting Information (SI) Section 2.

2.2. Data collection

Mobile monitoring was conducted with the Tufts Mobile Air Pollution Monitoring Laboratory (TAPL), a gasoline-powered vehicle that was driven on fixed routes (not on I-93) in each neighborhood (Fig. 1; details in SI 2 and Padró-Martínez et al., 2012). Each route took 40–60 min to complete and was driven in 2–6 h shifts on each day of monitoring. Monitoring was conducted on 35–47 days (85–281 h) in each neighborhood in the morning, afternoon, and evening in winter, spring, summer, and fall on non-consecutive days selected to maximize variability in meteorological and traffic conditions (Table 2, Table S1). In Somerville and Dorchester, the near-highway and urban background areas were close enough that they could be monitored on the same day; however, Chinatown (near-highway) and Malden (background) were too far apart to monitor both neighborhoods on the same day (11 km), so monitoring in these two neighborhoods was conducted up to 8 days apart (mean difference = 2 days). The TAPL measured PNC, NO, NO_X, CO, BC, particle-bound polycyclic aromatic hydrocarbons (pPAH), and fine particulate mass ($PM_{2.5}$; Table S2). Measurement averaging times ranged from 1-s (PNC) to 60-s (BC) and the distance between measurements was 5–600 m. Quality control measures included side-by-side instrument comparisons, flow checks, and lag-time corrections. To avoid inclusion of measurements tainted by self-sampling of exhaust from the TAPL, data were censored for TAPL speeds <5 km/h (~14% of data was censored). In Chinatown, correction of the GPS coordinates was sometimes necessary due to weak satellite signals in street canyons.

Meteorological, traffic, and geographical data were obtained from public datasets and assigned to each pollutant measurement using SAS 9.2 (see Fig. 1 for site locations). Wind speed and direction (7.9 m above ground level) and temperature (2 m above ground level) were measured at Logan International Airport (NCDC, 2012). This meteorological station was selected because of high data completeness across all three years of monitoring (~99%), and provides a better estimate of regional meteorology than of local meteorology, especially in the case of Chinatown where there are many street canyons. Hourly highway traffic counts and speed were measured by the Massachusetts Department of Transportation using remote traffic microwave sensors (model X3; stakeholder.traffic.com). Distance to highway edge was obtained by conducting spatial joins of measurement locations with a highway polygon in ArcGIS (Lane et al., 2013).

2.3. Data analysis

To determine whether monitoring in the three study areas in different years impacted our results, we compared hourly measurements of CO, NO, and NO_X and daily measurements of $PM_{2.5}$ collected continuously throughout the 3-year study period at the

Table 1
Study areas.

Area	Area (km^2)	Interstate highways	Other major roads[a]	Local diesel sources[b]	Buildings and roadside structures	Topographic features[c]
Somerville	2.3	I-93 (elevated in parts as much as 6 m, curves SE of study area)[d]	MA-28 (50); Broadway (14)	Trucks <500 vpd; 200 trains/day ~100 m NE of background area	Residences (~10-m high); 400-m-long noise barrier east of I-93 (3-m high)	17 m hill east of I-93; 41 m hill between near-highway and urban background areas
Dorchester	1.5	I-93 (3–6 m below grade)	Dorchester Ave (20), Old Colony Rd (36), Columbia Rd (20), and Adams St (9)	<500 vpd; 110 trains/day adjacent to west side of I-93	Residences (~10 m high); noise barrier along west side of I-93 (5-m-high)	34 m hill east of I-93; east to west elevation increase from 0 m to 30 m
Chinatown	0.5	I-93 (at-grade),[e] I-90 (below grade)	All other roads on the TAPL route (2 or 9)	<500–1000 vpd; buses plus 347 trains/day[f]	Residences and commercial buildings (up to 100-m tall); street canyons[g]	2–8 m above sea level
Malden	0.7	None	MA-60 (20)	<500 vpd, 58 trains/day	Residences (mostly ~0 m high, some 6-8 story apartments)	7–18 m above sea level

[a] Other highways and major roads in the study areas with their average daily traffic in thousands of vehicles per day from MassGIS (2008b).
[b] Diesel truck volumes from Callahan (2012) and Central Transportation Planning Staff (2012). Estimated diesel train volumes are the total of commuter (http://www.mbta.com/uploadedfiles/documents/2014%20BLUEBOOK%2014th%20Edition.pdf) and AMTRAK (http://www.amtrak.com/train-schedules-timetables) trains near and in the study areas.
[c] Elevation data was obtained from the Massachusetts Digital Elevation Model (MassGIS, 2005). Building heights and number of floors from http://skyscraperpage.com/cities/maps/?cityID=145.
[d] The I-93 corridor in Somerville also includes Mystic Avenue, which contributes 30,000 vehicles per day (vpd) at-grade (Central Transportation Planning Staff, 2012).
[e] The I-93 central artery tunnel comes above-ground just northeast of the study area, and I-93 is elevated along the study area.
[f] A train and bus depot (South Station) is located east of I-93 near the study area and commuter rail (diesel) train tracks run along I-90 southeast of the study area.
[g] The tallest two buildings in the Chinatown study area are 92 m (25 stories) and 79 m (23 stories).

Table 2
Summary of monitoring years and site conditions during monitoring.

		Somerville	Dorchester	Chinatown	Malden
Year		9/2009–8/2010	9/2010–8/2011	8/2011–7/2012	8/2011–7/2012
# of Monitoring days		44	35	47	36
# of Monitoring hours		281	173	141	85
# of April–October hours[a]		152	90	83	57
# of November–March hours[a]		129	83	58	28
Parameter					
Wind speed, m/s[b]		2.6 (1.6)	3.0 (2.1)	2.9 (1.6)	2.4 (1.3)
Temperature, °C[b]		11.1 (16.6)	9.2 (11.1)	14.4 (10.6)	14.8 (13.8)
Day of week, percent of full dataset	Sun	6%	10%	10%	2%
	Mon	8%	11%	4%	8%
	Tues	18%	10%	19%	11%
	Wed	27%	24%	20%	33%
	Thurs	24%	15%	13%	32%
	Fri	4%	17%	21%	9%
	Sat	14%	12%	14%	5%
I-93 Traffic volume, vph[b]		8500 (1800)	9600 (1000)	9600 (1400)	N/A
I-93 Traffic speed, kph[b]		83 (29)	86 (15)	86 (16)	N/A
I-90 Traffic volume, vph[b]		N/A	N/A	7100(3500)	N/A
I-90 Traffic speed, kph[b]		N/A	N/A	90 (5)	N/A

[a] Monitoring hours are split into warm (April to October) and cold (November to March) months.
[b] Data are summarized by mean with interquartile range in parentheses.

EPA Speciation Trends Network site (EPA-STN; ID: 25-025-0042) in Boston. This site is located ~1500 m west of I-93 and in a mixed residential and commercial area (Fig. 1; MA DEP, 2012). Interannual differences in CO, NO, NO_X, and $PM_{2.5}$ between September 2009 and July 2012 were tested using a multiple comparison Kruskal–Wallace test at the 95% confidence level (Giraudoux, 2013; Graves et al., 2012). To test for potential bias due to monitoring on different days in Chinatown and Malden, NO, NO_X, and CO measurements collected at the EPA-STN site during the hours of monitoring in the two neighborhoods were compared using the Kruskal–Wallace tests at the 95% confidence interval. $PM_{2.5}$ data were only available for every third day and were therefore not included in the analysis comparing monitoring days in Chinatown and Malden.

The one-sided Wilcoxon rank sum test (95% CI) was used to determine whether near-highway pollutant concentrations were statistically higher than concentrations in the paired urban background area. Spatial gradients in the near-highway areas were visualized with loess smoothing windows (spans) between 0.10 and 0.75. The spans with the least smoothing (smallest span) that had little noise were presented with 95% confidence intervals from generalized additive models (GAMs; Hastie, 2013). Smooths are presented instead of scatterplots because the large number of points (>160,000 per study area) interferes with scatterplot readability and interpretability.

The effects of temporal factors including meteorology and traffic volume on air pollutant concentrations were explored using several visualization tools. Loess smooths and boxplots were used to explore the impacts of individual factors like temperature and wind speed. Polar plots were used to explore the joint effects of wind speed and wind direction on pollutant concentrations (Carslaw and Ropkins, 2012).

Spearman correlations were calculated between hourly median pollutant concentrations in each near-highway and urban background area to reduce the impact of individual spikes. Spearman correlations were also generated for different times of the day as well as for different seasons. These correlations may change over short time periods due to differences between fresh and aged pollutants; therefore, the sensitivity of correlations to aggregation time was tested by comparing Spearman correlations for hourly medians with those for monthly, daily, and 1-min medians for a subset of the data. The 1-min aggregation time matched the resolution of the BC monitor, which had the longest reporting interval of all the monitors. All statistical analyses were performed in R (R Core Team, 2013).

3. Results

3.1. Effects of non-simultaneous monitoring

Differences related to non-simultaneous monitoring as measured at the EPA-STN site in Boston were small or statistically insignificant; therefore, we did not adjust our measurements to reflect the non-simultaneous measurement periods. Interannual differences in median NO, NO_X, CO, and $PM_{2.5}$ concentrations measured at the EPA-STN site were low: <2 ppb, <2 ppb, <5 ppb, and <0.1 μg/m^3, respectively (Fig. 2). $PM_{2.5}$ was statistically the same across all three years (Kruskal–Wallace multiple comparisons, $p = 0.89$). There was also no statistical difference between NO_X in the first two years or CO in the second two years ($p > 0.05$ for all). Trends in concentrations of CO, NO, and NO_X were not expected to affect the comparison among neighborhoods (all changed at a rate of <3 ppb/year; $p < 0.001$), and there was no statistically significant trend in $PM_{2.5}$ ($p > 0.99$). In comparing NO, NO_X, and CO concentrations at the EPA-STN site during the hours of non-simultaneous monitoring in Chinatown and Malden, there was no significant difference in NO or NO_X (Kruskal–Wallace multiple comparisons, $p = 0.23$ and 0.87, respectively); however, CO concentrations were higher during monitoring in Malden ($p = 0.03$; Fig. S2). The median CO concentrations measured at the EPA-STN site were 232.6 ppb during the hours of monitoring in Chinatown and 265.0 ppb during the hours of monitoring in Malden. This difference suggests there may have been some bias in the CO results: as much as 25% of the difference between Malden and Chinatown CO (Table 3) can be attributed to monitoring on different days in the two neighborhoods.

3.2. Spatial differences

Near highway – urban background contrasts were not the same for all pollutants in all neighborhoods. In Somerville and Chinatown, concentrations of all seven pollutants were higher near I-93 compared to urban background; however, in Dorchester only PNC, pPAH, and BC were higher near I-93 compared to background (Wilcoxon rank sum test, $p < 0.001$) (Table 3; Fig. 3). In Dorchester the median concentrations of NO_X and NO were not statistically different near I-93 compared to background, and median concentrations of CO and $PM_{2.5}$ were actually higher in the background area than near the highway. The highest concentrations of gaseous pollutants in Dorchester tended to occur when winds were from the west (Fig. S3). Empirical cumulative distributions in Fig. 3 show that intra-neighborhood differences were greater than inter-neighborhood differences for PNC and pPAH, while for CO, NO, NO_X, $PM_{2.5}$, and BC inter-neighborhood differences were greater than intra-neighborhood differences. In addition, Dorchester had particularly high levels of NO, NO_X, and CO and low levels of BC compared to the other neighborhoods.

Pollutant distance-decay gradients generally reached background within 200 m of I-93 when significant local sources were absent; therefore, 200 m was used as the cutoff for near-highway gradient calculations. Distance-decay gradients near I-93 were different for each near-highway neighborhood, with the steepest gradients occurring in Somerville and Dorchester (Fig. 4). In Somerville and Dorchester PNC decreased by 34% and 30%, respectively, between 0 and 200 m from I-93, while the PNC distance-decay gradient in Chinatown was generally flat (2%; Table 4). Similarly, pPAH also decreased more in Dorchester (44%) and Somerville (39%) compared to Chinatown (21%). Somerville had the most pollutants with decreases of >20% within the first 200 m from I-93: PNC, BC, NO, NO_X, and pPAH. In Dorchester, only PNC and pPAH decreased by >20%. In Chinatown, CO, NO, and pPAH decreased by ~21% and all other pollutants either decreased by <20% (PNC, BC, NO_X) or increased ($PM_{2.5}$). The gradients from I-93 were stronger than those from I-90 in Chinatown: BC decreased by 8% and PNC decreased by 1%, while CO, NO, and NO_X increased by <8.3% over 200 m from I-90 and neither pPAH nor $PM_{2.5}$ had a significant trend over the same distance (Fig. S4). In all three neighborhoods, PNC and pPAH had statistically significant distance-decay gradients within 200 m of I-93. In some cases, increasing pollutant concentrations with distance from I-93 were observed at distances greater than 200 m. In addition to those pollutants already mentioned, PNC and pPAH increased from 200 to 400 m west of I-93 in Dorchester as distance to a major urban roadway (Dorchester Avenue) decreased.

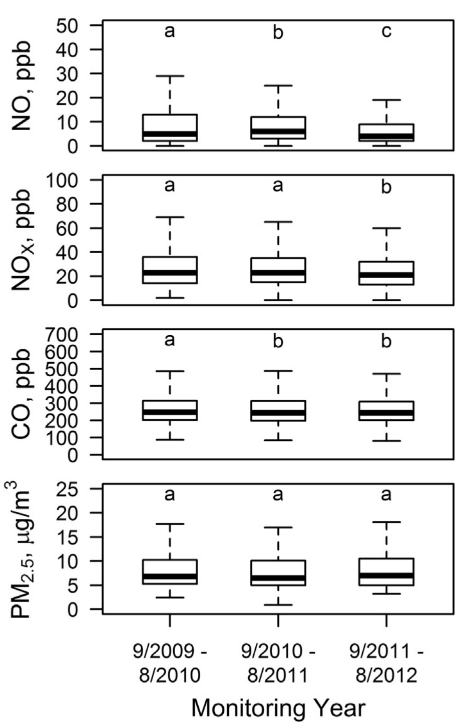


Fig. 2. Tukey boxplots comparing NO, NO_X, CO, and $PM_{2.5}$ measured at STN site 25-025-0042 in Boston (Fig. 1) for each full mobile monitoring year. Whisker lengths are the smaller value of 1.5*IQR and the distance to the maximum or minimum (outliers not shown). Common letters above the boxes for each pollutant identify groups that are not significantly different at the 95% confidence interval using Kruskal–Wallace multiple comparisons test. Data is from MA DEP (2012).

3.3. Temporal differences

The effects of I-93 traffic volume were not the same for all pollutants in the three near-highway neighborhoods. PNC increased sharply in the three neighborhoods when traffic volumes were >~9000 vehicles/hr (Fig. S5), particularly during the morning rush hour when winds were lightest and (presumably) mixing height was lowest. Also, $PM_{2.5}$ generally increased with traffic volume in the three neighborhoods, and pPAH, CO, NO, and NO_x increased with traffic volume in Dorchester. In contrast, compared to differences among the neighborhoods, BC was largely unchanged with traffic volume, and pPAH, CO, NO, and NO_x concentrations were relatively unchanged as traffic increased in Somerville and Chinatown.

The effects of temperature on pollutant concentrations were similar for all neighborhoods. Temperature is an independent factor affecting air pollution formation and removal rates as well as a proxy for other seasonal factors (e.g., photochemical activity, mixing height). Temperature most strongly affected PNC and $PM_{2.5}$, which were highest in winter and summer, respectively (Fig. S6). Other pollutants (CO, NO, NO_X, pPAH, BC) had small or non-monotonic changes with temperature. Likewise, the effects of wind speed were similar for all neighborhoods: concentrations generally decreased with increasing wind speed (Figs. S3 and S7). Exceptions were $PM_{2.5}$ in Somerville and BC in Somerville and

Table 3
Summary of pollutant measurements for each study area.

	Somerville[a]			Dorchester[a]			Chinatown/Malden[a]		
	NH	UB	P[b]	NH	UB	P[b]	NH	UB	P[b]
CO, ppb	390 (310)	310 (230)	<0.001	600 (420)	660 (450)	1[c]	460 (380)	344 (280)	<0.001
NO, ppb	15 (26)	6 (11)	<0.001	31 (50)	32 (46)	0.50	16 (24)	8 (15)	<0.001
NO_X, ppb	33 (39)	20 (20)	<0.001	67 (56)	71 (54)	0.55	36 (35)	20 (27)	<0.001
pPAH, fA	8 (12)	4 (6)	<0.001	5 (8)	3 (5)	<0.001	8 (11)	3 (5)	<0.001
PNC, 1000 cm^{-3}	30 (49)	18 (19)	<0.001	27 (33)	19 (20)	<0.001	26 (26)	14 (20)	<0.001
$PM_{2.5}$, μg m^{-3}	15 (23)	14 (17)	<0.001	13 (8)	14 (7)	1[c]	14 (9)	12 (9)	<0.001
BC, μg m^{-3}	0.8 (0.9)	0.5 (0.5)	<0.001	0.4 (0.4)	0.3 (0.3)	<0.001	0.8 (0.9)	0.5 (0.5)	<0.001

[a] Median pollutant levels with IQR in parentheses for NH = near-highway (<400 m from edge of I-93) and UB = urban background (>1000 m from edge of I-93) areas.
[b] P-values are based on Wilcoxon rank sum test of the null hypothesis that near-highway concentrations are ≤ urban background concentrations.
[c] Urban background concentrations were statistically significantly greater than near-highway concentrations.

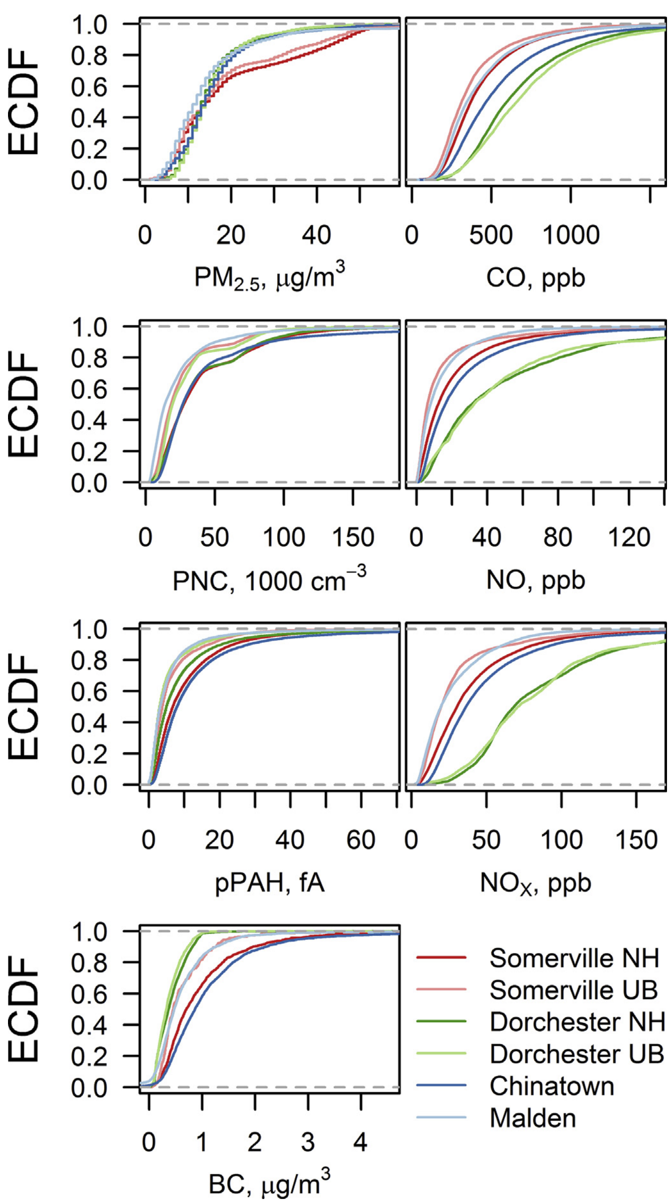


Fig. 3. Empirical cumulative distribution functions for particles (left side: $PM_{2.5}$, PNC, pPAH, BC) and gases (right side: CO, NO, NO_X) for Somerville near-highway (NH) and urban background (UB), Dorchester near-highway and urban background, Chinatown near-highway, and Malden urban background study areas. The *x*-axis maxima were set at the 99th percentile of near-highway measurements in Somerville.

Dorchester, which increased in both magnitude and variability at wind speeds above ~6 m/s.

Effects of wind direction were different in each neighborhood. While the monitored near-highway areas generally had elevated pollutant concentrations when they were downwind of I-93, some areas also had high pollutant concentrations when the wind came from other directions (Fig. S3). These differences were clearest for PNC, which had high concentrations for southeast winds in Somerville and Malden, northeast winds in Dorchester, and north and east winds in Chinatown. In Dorchester, concentrations of CO, NO, and NO_X were 2–4 times higher than in other neighborhoods and tended to be highest for westerly winds (i.e., as high as 900 ppb CO, 60 ppb NO, and 100 ppb NO_X). In Chinatown, pollutant concentrations in the Washington Street canyon (which runs north-south) were highest for south winds from the direction of I-90 and lowest for north winds and west winds (Fig. 5). Differences in concentrations for different wind directions were largest for $PM_{2.5}$ and smallest for NO and NO_X.

3.4. Inter-pollutant correlations

Inter-pollutant correlations varied by neighborhood. Spearman correlations were higher among the gases (NO, NO_X, and CO) and lower among particulate pollutants (Fig. 6). PNC was more highly correlated with the gases than with measures of particle mass. The correlations of NO with NO_X were consistently high in both near-highway and urban background areas in Somerville, Dorchester, and Chinatown/Malden. In general, correlations were lower in Dorchester than in other areas; the only correlation greater than 0.7 in the Dorchester near-highway area was for NO and NO_X (0.93). In contrast, the Somerville near-highway area had high correlations for many pollutant pairs, including NO_X and CO (0.76), NO_x and pPAH (0.83), and NO_x and PNC (0.80). As expected, $PM_{2.5}$ was not highly correlated with other pollutants in any of the study areas. Inter-pollutant correlations also varied by season and time of day: correlations were higher in cold months (November to March) than in warm months (April to October; Fig. 7), and correlations were high during the morning rush hour (particularly when winds were light), low during the middle of the day, and high again during the afternoon rush hour (Fig. 8).

A sensitivity analysis performed with the Chinatown data demonstrated that correlations were sensitive to aggregation times: correlations were usually higher for daily and hourly medians compared to 1 month and 1 min medians (Fig. S8). Most inter-pollutant correlations were highest for measurements aggregated by day, although correlations of $PM_{2.5}$ with BC, PNC, and pPAH and of pPAH with BC were highest for monthly aggregation.

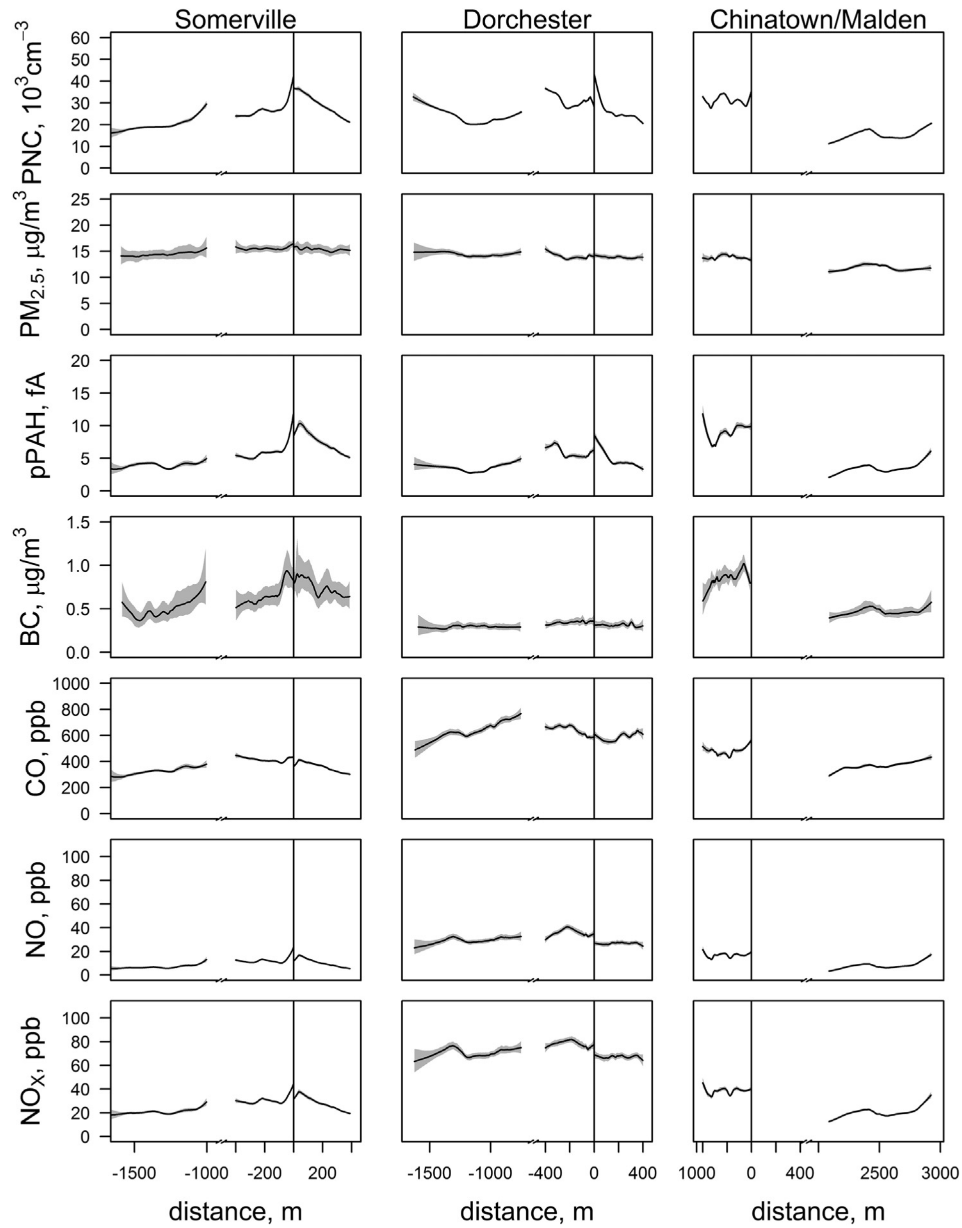


Fig. 4. Loess smooths (black lines) with 95% confidence intervals (gray shading) for PNC, $PM_{2.5}$, pPAH, BC, CO, NO, and NO_X, as a function of distance from the nearest edge of I-93 (vertical black lines) for Somerville (left), Dorchester (center), and Chinatown/Malden (right). Each plot has a break between the near-highway and urban background. The only urban background area east of I-93 is Malden. Distances east of I-93 are positive and distances west of I-93 are negative.

4. Discussion

We compared spatial and temporal TRAP trends in three near-highway and three urban background neighborhoods in a single urban corridor. Although each neighborhood had similar levels of local and diesel traffic and mobile source pollution and low levels of industrial or power plant emissions (Callahan, 2012; MassGIS, 2008a; U.S. Energy Information Administration, 2014), there were different spatial patterns in TRAP concentrations and inter-pollutant correlations. TRAP concentrations generally increased with highway proximity, consistent with I-93 as a major source; however, distance-decay gradients varied by neighborhood in addition to season and time of day. In general, our results are consistent with studies that have reported pronounced distance-decay gradients of TRAP <200 m from highways and higher concentrations of TRAP near highways than in urban background neighborhoods (Durant et al., 2010; Hu et al., 2012; Kassomenos et al., 2014; Kittelson et al., 2004; Zhu et al., 2009). Previous studies have reported differences in air pollution in different neighborhoods (e.g., Bereznicki et al., 2012; Duvall et al., 2012; Fruin et al., 2014; Kassomenos et al., 2014); however, these differences were generally attributed to local sources such as industrial plants, power generation, or marine shipping terminals. Unlike Fruin et al. (2014), we found only small differences in $PM_{2.5}$ (≤ 3 µg/m^3) between neighborhoods, possibly because of the more substantial regional contribution to $PM_{2.5}$ in the Boston area relative to Southern California, as well as because the neighborhoods we monitored were closer together on average (1–30 km) than those in California (4–100 km).

Neighborhood geography including highway elevation and curvature, near-highway structures, and surface roads may help to explain observed differences in spatial variation of TRAP in the

Table 4
Distance-decay gradients of pollutant concentration within 200 m of highway edge.

	Somerville: I-93			Dorchester: I-93			Chinatown: I-93			Chinatown: I-90		
	Estimate[a]	Decrease, %[b]	p[c]	Estimate[a]	Decrease, %[b]	p[c]	Estimate[a]	Decrease, %[b]	p[c]	Estimate[a]	Decrease, %[b]	p[c]
PNC	−0.204	**34**	<0.001	−0.176	**30**	<0.001	−0.011	2	0.003	−0.005	1	<0.001
BC	−0.17	**29**	0.0007	−0.03	6	0.4	−0.02	4	0.7	−0.04	8	0.001
CO	−0.007	1	0.3	0.009	−2	0.3	−0.121	**21.5**	<0.001	0.040	−8.3	<0.001
NO	−0.21	**34**	<0.001	−0.01	2	0.6	−0.12	**21**	<0.001	0.021	−4.3	<0.001
NO_X	−0.130	**23**	<0.001	−0.01	2	0.4	−0.07	10	<0.001	0.012	−2.4	<0.001
pPAH	−0.25	**39**	<0.001	−0.29	**44**	<0.001	−0.12	**21**	<0.001	0.002	−0.4	0.7
$PM_{2.5}$	−0.02	4	0.09	−0.016	3.1	0.08	0.029	−6.0	<0.001	−0.001	0.2	0.8

[a] Estimate is the % change in the logarithm of the pollutant concentrations per 100 m away from the edge of the highway. It was obtained by multiplying the coefficient of the simple log-linear regression of concentration as a function of distance times 100.
[b] The percent decrease over 200 m is calculated as 100*[exp(Estimate/100*200) − 1] (Wooldridge, 2012). Decreases ≥20% are bold.
[c] P-value for the Estimate coefficient.

study neighborhoods. In Somerville, the influence of the elevated section of I-93 was larger than that of I-93 in Dorchester and I-90 in Chinatown, where the highway influence was likely reduced because the highways were below-grade (Steffens et al., 2014). Highway sections with large curvature (e.g., I-93 at the southeast border of Somerville) potentially contributed to increased peak concentrations due to larger effective traffic volumes. On the other hand, noise barriers may have decreased peak concentrations east of I-93 in Somerville and west of I-93 in Dorchester (Finn et al., 2010; Hagler et al., 2012; Ning et al., 2010). In Chinatown, street-canyons between tall buildings may have altered wind flow so that meteorological data from Logan Airport was not representative of wind direction and speed within the study area. The general results in Chinatown, particularly for winds from the south, were consistent with entrainment of highway-generated TRAP in a street canyon (Kumar et al., 2008). In addition, examination of concentration patterns indicated contributions from major surface roads were often comparable in magnitude to contributions from highways. This effect was largest in Dorchester and Chinatown, where at-grade traffic on major roads may have had more influence than direct emissions from I-93 and I-90. For example, Kneeland St and E Berkeley St contribute to air pollution in Chinatown because they provide access to highway ramps and have high-volume intersections (Massachusetts Bay Transportation Authority, 2005).

Although monitoring in all three near-highway areas was conducted over a similar range of meteorological and traffic conditions, some differences in pollutant concentrations and distance-decay gradients in the neighborhoods could not be explained by highway traffic data or data from the regional meteorological station. Traffic on local roadways may explain some of those differences, particularly in Dorchester, where CO and NO_X concentrations were consistently higher than in other neighborhoods. Our study was not designed to formally capture sources other than highway vehicles, but evidence regarding different wind direction effects in the different neighborhoods can be used to generate hypotheses regarding important non-highway sources. For example, high PNC

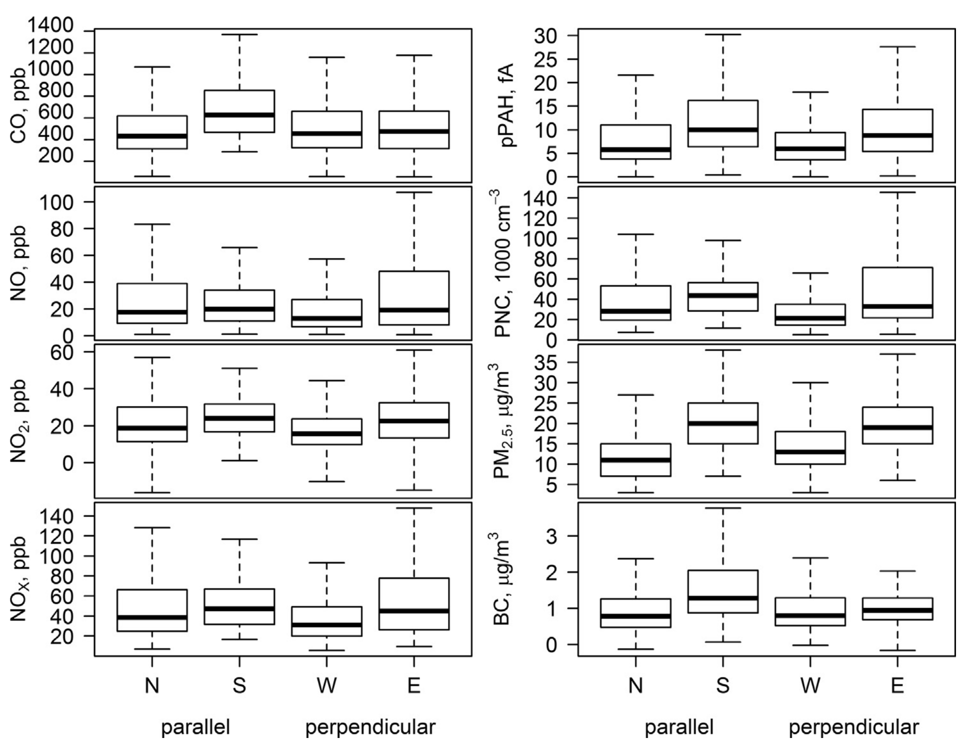


Fig. 5. Tukey boxplots of CO, NO, NO_2, NO_X, pPAH, PNC, $PM_{2.5}$, and BC concentrations on Washington Street (street canyon in Chinatown) as a function of wind direction relative to the street orientation. Whisker lengths are the smaller value of 1.5*IQR and the distance to the maximum or minimum (outliers not shown).

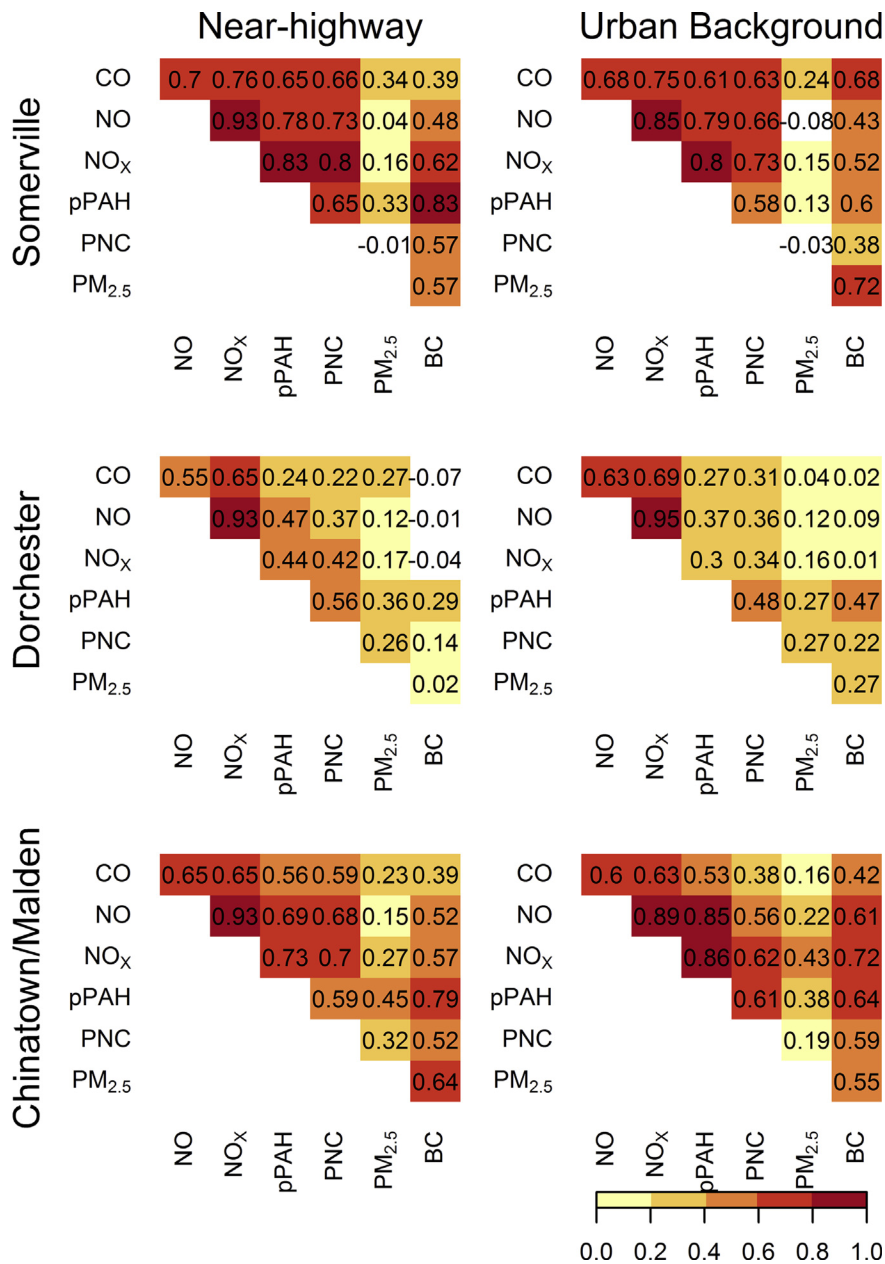


Fig. 6. Spearman correlations of pollutants (hourly median) by study area.

occurred for wind directions (including southeast in Somerville and Malden, northeast in Dorchester, and east in Chinatown) when the neighborhoods were downwind of downtown Boston and Logan Airport, which contain several potential emissions sources including surface transportation (roads and rail) and aircraft.

Correlations were generally strongest during times when there were high levels of fresh emissions (e.g., during rush hour) and during colder months (October–May). Higher correlations during cold months are consistent with the literature and may also be related to more favorable formation conditions for certain pollutants (e.g., ultrafine particles), greater atmospheric stability and lower photochemical activity during cooler times of the year (Kittelson et al., 2004; Kumar et al., 2014; Venkatram et al., 2013). These differences are unlikely to be related to traffic volume, which differed by $\leq$3% between warm and cold seasons. Correlations are useful to test our understanding of the sources and mixing; correlations among pollutants emitted from the same source should be high, while lower correlations may indicate another source or the presence of aged TRAP. Higher inter-neighborhood variation of $PM_{2.5}$ than intra-neighborhood variation (one-way ANOVA) and generally low correlations of $PM_{2.5}$ with the other pollutants suggest that $PM_{2.5}$ was more regional while the other pollutants had local sources, consistent with expectations.

There were limitations in our data collection and analysis methods. First, the study was conducted with hourly meteorological data from a single weather station that was ~4–12 km from the study areas. Local wind effects such as wind tunnels between rows of buildings were not captured by the station at Logan Airport. Second, traffic parameters were based on highway counts. TRAP sources that are not captured in the available datasets (e.g., diurnal variation in congestion and diesel traffic on local roads) may also

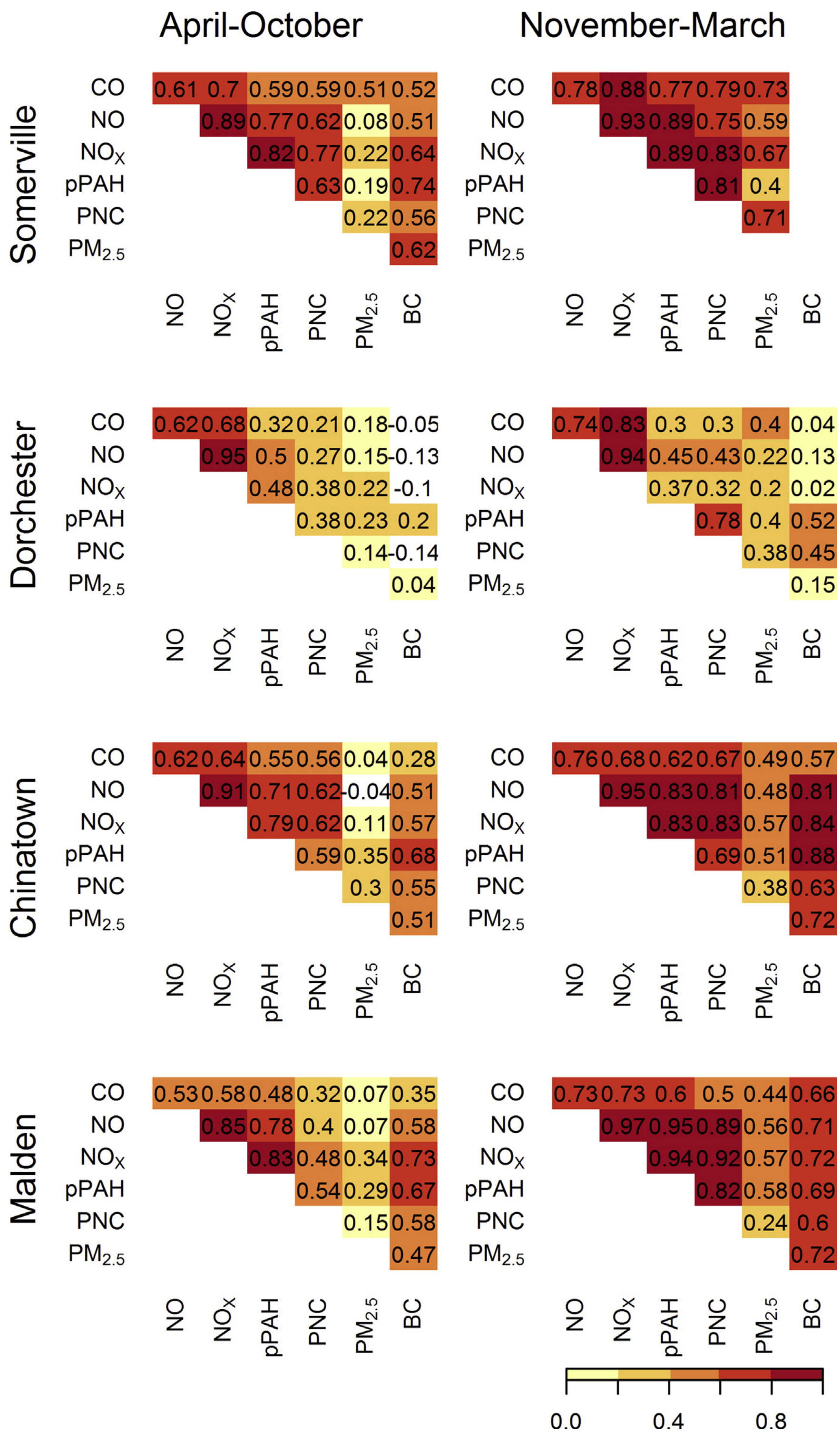


Fig. 7. Spearman correlations for warm (April to October) and cold (November to March) months for Somerville, Dorchester, Chinatown, and Malden. The BC monitor was not running during the cold months in Somerville.

explain some of the observed inter-neighborhood differences. Third, distance-decay gradients measured by the mobile laboratory for pollutants with longer measurement times (BC, NO, NO_X, CO) may be underestimated; therefore, comparison of distance-decay gradients would possibly have yielded different results had all the monitors recorded measurements at the same frequency. These limitations do not significantly affect our main result that there are both intra- and inter-neighborhood differences in TRAP along I-93 in the Boston area.

The finding that the near-highway neighborhoods are different in terms of TRAP has two main implications for health studies in small areas. First, distance-decay gradients measured in one near-highway neighborhood are not necessarily transferable to other neighborhoods, even along the same highway in a metropolitan

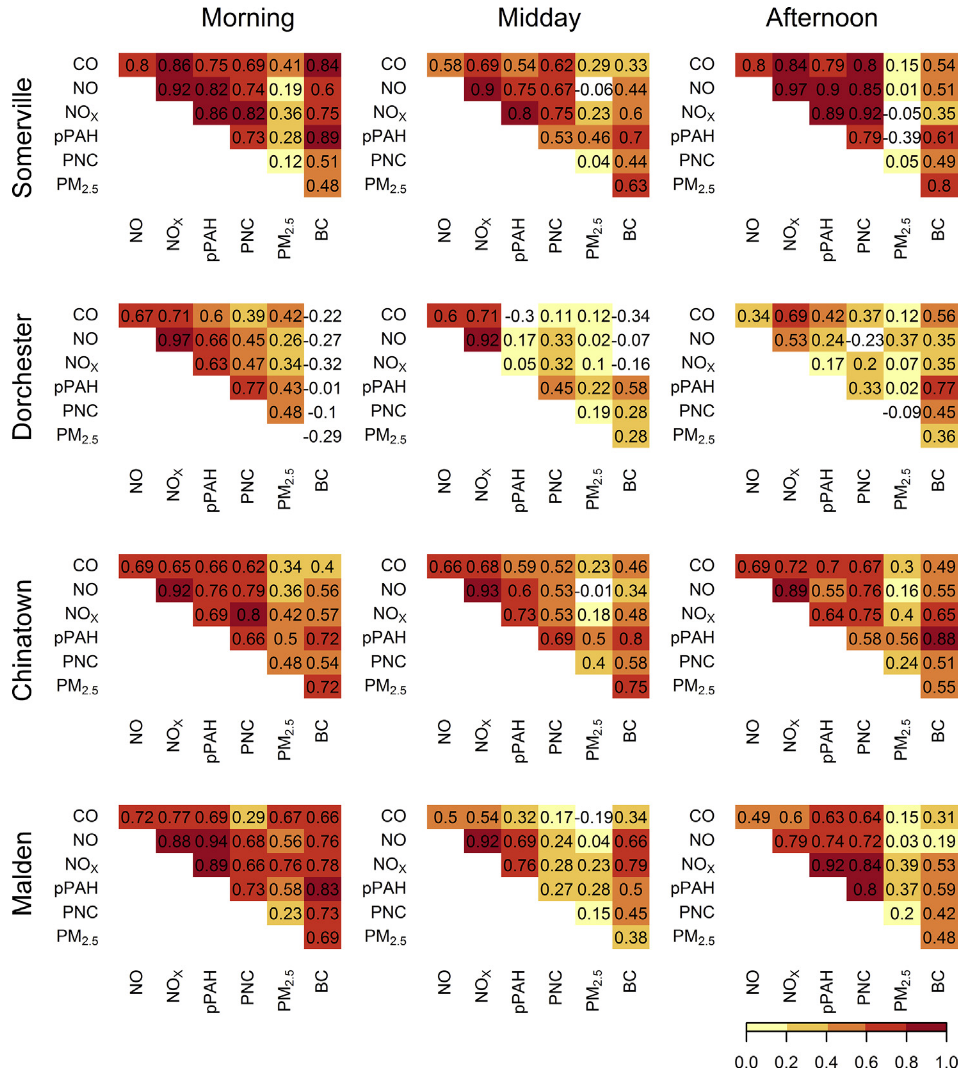


Fig. 8. Spearman correlations in each study area by time of day. Morning = 04:30–10:00, Midday = 10:00–14:00, and Afternoon = 14:00–22:00.

area. In health studies involving comparison of different neighborhoods, monitoring in multiple locations at different times may be required to characterize gradients particularly where there are (1) pronounced changes in highway grade or curvature, or (2) changes in near-highway structures, vegetation, and building height or density. Second, consideration of multiple pollutants may be necessary given that the causal pollutant(s) within TRAP have not yet been delineated. Using a single surrogate pollutant may lead to differential error across neighborhoods, as the surrogate will represent different combinations of pollutants across locations. The variable patterns within a day suggest that these differences may be particularly important in short-term studies, which will need to account for multi-pollutant correlations that change in both space and time.

5. Conclusions

Our results indicate that generalizability of near-road gradients and near-highway/urban background contrasts is limited for near-highway neighborhoods in a metropolitan area with substantial mobile source emissions. Near-highway distance-decay gradients of TRAP concentrations and inter-pollutant correlations were not the same in different neighborhoods along a single highway through an urban area. Differences were not completely explained by temporal variation, including traffic patterns or seasonal or diurnal effects. These differences may be related to local infrastructure, traffic congestion, and non-traffic sources of air pollution. Our results suggest that caution should be used when assuming similarity of near-highway areas for epidemiological studies because even measuring several gradients at different locations along a highway may underestimate the true variability in distance-decay gradients in urban areas. These findings may be particularly relevant for metropolitan areas like Boston where, due to roadside structures, highway geometry, and local wind and traffic patterns, near-highway neighborhoods will exhibit dissimilar air pollution impacts from mobile sources.

Acknowledgments

This work was done as part of the Community Assessment of Freeway Exposure and Health (CAFEH) study, a CBPR project. The CBPR Community Partners were the Somerville Transportation Equity Partnership, the Committee for Boston Public Housing, the Chinatown Resident Association, and the Chinese Progressive Association. Jeffrey Trull, Kevin Stone, Piers MacNaughton, Eric Wilburn, Andrew Shapero, Samantha Weaver, Alex Bob, and Dana

Harada contributed to the data collection and processing effort. Tina Wang and Baolian Kuang provided local knowledge on Chinatown and Kevin Stone provided local knowledge on Somerville. We would like to thank the members of the CAFEH Steering Committee: Ellin Reisner, Boalian Kuang, Lydia Lowe, Edna Carrasco, M. Barton Laws, Yuping Zeng, Michelle Liang, Christina Hemphill Fuller, Mae Fripp, Kevin Lane, and Mario Davila. We are also grateful to George Allen at NESCAUM for the generous loan of the aethalometer. This research was supported by NIEHS (ES015462) and the Jonathan M. Tisch College of Citizenship and Public Service (through the Tufts Community Research Center). APP was partially supported by the US EPA (FP-917203), NIEHS (T32 ES198543), and a P.E.O. Scholar award. This work has not been reviewed by any governmental agency. The views expressed are solely those of the authors, and governmental agencies do not endorse any products or commercial services mentioned in this paper.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.atmosenv.2014.09.072.

References

Bereznicki, S.D., Sobus, J.R., Vette, A.F., Stiegel, M.A., Williams, R.W., 2012. Assessing spatial and temporal variability of VOCs and PM-components in outdoor air during the Detroit Exposure and Aerosol Research Study (DEARS). Atmos. Environ. 61, 159–168.

Brugge, D., Durant, J.L., Rioux, C., 2007. Near-highway pollutants in motor vehicle exhaust: a review of epidemiologic evidence of cardiac and pulmonary health risks. Environ. Health: A Glob. Access Sci. Source 6.

Callahan, M., 2012. Memorandum: Results of the Boston Region MPO's 2010 Freight Study – a Profile of Truck Impacts. Boston Region Metropolitan Planning Organization.

Carslaw, D.C., Ropkins, K., 2012. Openair – an R package for air quality data analysis. Environ. Model. Softw. 27–28, 52–61.

Central Transportation Planning Staff, 2012. Average Daily Traffic on Massachusetts Roads, CTPS Geoserver. http://www.ctps.org/geoserver/www/apps/adtApp/index.html.

Clougherty, J.E., Wright, R.J., Baxter, L.K., Levy, J.I., 2008. Land use regression modeling of intra-urban residential variability in multiple traffic-related air pollutants. Environ. Health: A Glob. Access. Sci. Source 7, 17.

Dons, E., Temmerman, P., Van Poppel, M., Bellemans, T., Wets, G., Int Panis, L., 2013. Street characteristics and traffic factors determining road users' exposure to black carbon. Sci. Total Environ. 447, 72–79.

Durant, J.L., Ash, C.A., Wood, E.C., Herndon, S.C., Jayne, J.T., Knighton, W.B., Canagaratna, M.R., Trull, J.B., Brugge, D., Zamore, W., Kolb, C.E., 2010. Short-term variation in near-highway air pollutant gradients on a winter morning. Atmos. Chem. Phys. 10, 8341–8352.

Duvall, R.M., Norris, G.A., Burke, J.M., Olson, D.A., Vedantham, R., Williams, R., 2012. Determining spatial variability in PM2.5 source impacts across Detroit, MI. Atmos. Environ. 47, 491–498.

Eeftens, M., Tsai, M.-Y., Ampe, C., Anwander, B., Beelen, R., Bellander, T., Cesaroni, G., Cirach, M., Cyrys, J., de Hoogh, K., De Nazelle, A., de Vocht, F., Declercq, C., Dėdelė, A., Eriksen, K., Galassi, C., Gra̧ulevičienė, R., Grivas, G., Heinrich, J., Hoffmann, B., Iakovides, M., Ineichen, A., Katsouyanni, K., Korek, M., Krämer, U., Kuhlbusch, T., Lanki, T., Madsen, C., Meliefste, K., Mölter, A., Mosler, G., Nieuwenhuijsen, M., Oldenwening, M., Pennanen, A., Probst-Hensch, N., Quass, U., Raaschou-Nielsen, O., Ranzi, A., Stephanou, E., Sugiri, D., Udvardy, O., Vaskövi, É., Weinmayr, G., Brunekreef, B., Hoek, G., 2012. Spatial variation of PM2.5, PM10, PM2.5 absorbance and PMcoarse concentrations between and within 20 European study areas and the relationship with NO_2 – results of the ESCAPE project. Atmos. Environ. 62, 303–317.

Finn, D., Clawson, K.L., Carter, R.G., Rich, J.D., Eckman, R.M., Perry, S.G., Isakov, V., Heist, D.K., 2010. Tracer studies to characterize the effects of roadside noise barriers on near-road pollutant dispersion under varying atmospheric stability conditions. Atmos. Environ. 44, 204–214.

Fruin, S., Urman, R., Lurmann, F., McConnell, R., Gauderman, J., Rappaport, E., Franklin, M., Gilliland, F.D., Shafer, M., Gorski, P., Avol, E., 2014. Spatial variation in particulate matter components over a large urban area. Atmos. Environ. 83, 211–219.

Fuller, C.H., Patton, A.P., Lane, K., Laws, M.B., Marden, A., Carrasco, E., Spengler, J., Mwamburi, M., Zamore, W., Durant, J.L., Brugge, D., 2013. A community participatory study of cardiovascular health and exposure to near-highway air pollution: study design and methods. Rev. Environ. Health 28, 21.

Gan, W., Tamburic, L., Davies, H., Demers, P., Koehoorn, M., Brauer, M., 2009. Change in residential proximity to traffic and risk of death from coronary heart disease. Epidemiology 20, S186–S187, 110.1097/1001.ede.0000362629.0000345350.e0000362623.

Giraudoux, P., 2013. Pgirmess: Data Analysis in Ecology. http://CRAN.R-project.org/package=pgirmess.

Graves, S., Piepho, H., Selzer, L., Dorai-Raj, S., 2012. multcompView: Visualizations of Paired Comparisons. http://CRAN.R-project.org/package=multcompView.

Hagler, G.S.W., Lin, M.-Y., Khlystov, A., Baldauf, R.W., Isakov, V., Faircloth, J., Jackson, L.E., 2012. Field investigation of roadside vegetative and structural barrier impact on near-road ultrafine particle concentrations under a variety of wind conditions. Sci. Total Environ. 419, 7–15.

Hagler, G.S.W., Thoma, E.D., Baldauf, R.W., 2010. High-resolution mobile monitoring of carbon monoxide and ultrafine particle concentrations in a near-road Environment. J. Air & Waste Manag. Assoc. 60, 328–336.

Hastie, T., 2013. Gam: Generalized Additive Models, R Package Version 1.08. http://CRAN.R-project.org/package=gam.

HEI, 2010. Traffic-related air pollution: a Critical review of the literature on emissions, exposure, and health effects. HEI Panel on the Health Effects of Traffic-related Air Pollution.

Hoek, G., Krishnan, R., Beelen, R., Peters, A., Ostro, B., Brunekreef, B., Kaufman, J., 2013. Long-term air pollution exposure and cardio- respiratory mortality: a review. Environ. Health 12, 43.

Hu, S., Paulson, S.E., Fruin, S., Kozawa, K., Mara, S., Winer, A.M., 2012. Observation of elevated air pollutant concentrations in a residential neighborhood of Los Angeles California using a mobile platform. Atmos. Environ. 51, 311–319.

Jerrett, M., Arain, A., Kanaroglou, P., Beckerman, B., Potoglou, D., Sahsuvaroglu, T., Morrison, J., Giovis, C., 2005. A review and evaluation of intraurban air pollution exposure models. J. Expo. Analysis Environ. Epidemiol. 15, 185–204.

Karner, A.A., Eisinger, D.S., Niemeier, D.A., 2010. Near-roadway air quality: synthesizing the findings from real-world data. Environ. Sci. Technol. 44, 5334–5344.

Kassomenos, P.A., Vardoulakis, S., Chaloulakou, A., Paschalidou, A.K., Grivas, G., Borge, R., Lumbreras, J., 2014. Study of PM10 and PM2.5 levels in three European cities: analysis of intra and inter urban variations. Atmos. Environ. 87, 153–163.

Kittelson, D.B., Watts, W.F., Johnson, J.P., 2004. Nanoparticle emissions on Minnesota highways. Atmos. Environ. 38, 9–19.

Kumar, P., Fennell, P., Britter, R., 2008. Effect of wind direction and speed on the dispersion of nucleation and accumulation mode particles in an urban street canyon. Sci. Total Environ. 402, 82–94.

Kumar, P., Morawska, L., Birmili, W., Paasonen, P., Hu, M., Kulmala, M., Harrison, R.M., Norford, L., Britter, R., 2014. Ultrafine particles in cities. Environ. Int. 66, 1–10.

Lane, K., Kangsen Scammell, M., Levy, J., Fuller, C., Parambi, R., Zamore, W., Mwamburi, M., Brugge, D., 2013. Positional error and time-activity patterns in near-highway proximity studies: an exposure misclassification analysis. Environ. Health 12, 75.

Lebret, E., Briggs, D., van Reeuwijk, H., Fischer, P., Smallbone, K., Harssema, H., Kriz, B., Gorynski, P., Elliott, P., 2000. Small area variations in ambient NO2 concentrations in four European areas. Atmos. Environ. 34, 177–185.

Levy, I., Mihele, C., Lu, G., Narayan, J., Brook, J.R., 2013. Evaluating multipollutant exposure and urban air quality: pollutant interrelationships, neighborhood variability, and nitrogen dioxide as a proxy pollutant. Environ. Health Perspect. 122, 65–72.

Levy, I., Mihele, C., Lu, G., Narayan, J., Hilker, N., Brook, J., 2014. Elucidating multipollutant exposure across a complex metropolitan area by systematic deployment of a mobile laboratory. Atmos. Chem. Phys. 14, 7173–7193.

MA DEP, 2012. Air Quality Monitoring Data from Site 25-025-0042. Massachusetts Department of Environmental Protection.

Massachusetts Bay Transportation Authority, 2005. Silver Line Phase III: Supplemental Draft EIS/EIR. Boston, MA. http://www.mbta.com/uploadedfiles/About_the_T/T_Projects/T_Projects_List/CH%204%20Final%20DEIS.pdf.

MassGIS, 2005. Digital Elevation Model (1:5,000), Office of Geographic and Environmental Information (MassGIS). Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs.

MassGIS, 2008a. EOTMAJROADS, Office of Geographic and Environmental Information (MassGIS). Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs.

MassGIS, 2008b. EOTROADS, Office of Geographic and Environmental Information (MassGIS). Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs.

McConnell, R., Islam, T., Shankardass, K., Jerrett, M., Lurmann, F., Gilliland, F., Gauderman, J., Avol, E., Kunzli, N., Yao, L., Peters, J., Berhane, K., 2010. Childhood incident asthma and traffic-related air pollution at home and school. Environ. Health Perspect. 118, 1021–1026.

McGahan, A., Quackenbush, K.H., Kuttner, W.S., 2001. Regional Truck Study. Boston Region Metropolitan Planning Organization, Central Transportation Planning Staff.

NCDC, 2012. Integrated Surface Hourly (ISH) Dataset, Logan International Airport. AWSMSC 725090, WBAN 14739. National Climate Data Center. ftp://ftp.ncdc.noaa.gov/pub/data/.

Ning, Z., Hudda, N., Daher, N., Kam, W., Herner, J., Kozawa, K., Mara, S., Sioutas, C., 2010. Impact of roadside noise barriers on particle size distributions and pollutants concentrations near freeways. Atmos. Environ. 44, 3118–3127.

Padró-Martínez, L.T., Patton, A.P., Trull, J.B., Zamore, W., Brugge, D., Durant, J.L., 2012. Mobile monitoring of particle number concentration and other traffic-related

air pollutants in a near-highway neighborhood over the course of a year. Atmos. Environ. 61, 253–264.
Pattinson, W., Longley, I., Kingham, S., 2014. Using mobile monitoring to visualise diurnal variation of traffic pollutants across two near-highway neighbourhoods. Atmos. Environ. 94, 782–792.
R Core Team, 2013. R: a Language and Environment for Statistical Computing, 2.13.1. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.
Roorda-Knape, M.C., Janssen, N.A.H., De Hartog, J.J., Van Vliet, P.H.N., Harssema, H., Brunekreef, B., 1998. Air pollution from traffic in city districts near major motorways. Atmos. Environ. 32, 1921–1930.
Steffens, J.T., Heist, D.K., Perry, S.G., Isakov, V., Baldauf, R.W., Zhang, K.M., 2014. Effects of roadway configurations on near-road air quality and the implications on roadway designs. Atmos. Environ. 94, 74–85.
U.S. Energy Information Administration, 2014. Massachusetts State Profile and Energy Estimates. http://www.eia.gov/state/?sid=MA.
Vardoulakis, S., Fisher, B.E., Pericleous, K., Gonzalez-Flesca, N., 2003. Modelling air quality in street canyons: a review. Atmos. Environ. 37, 155–182.
Venkatram, A., Snyder, M., Isakov, V., 2013. Modeling the impact of roadway emissions in light wind, stable and transition conditions. Transp. Res. Part D: Transp. Environ. 24, 110–119.
Wooldridge, J.M., 2012. Introductory Econometrics: a Modern Approach. Cengage Learning.
Zhou, Y., Levy, J., 2007. Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. BMC Public Health 7, 89.
Zhu, Y., Pudota, J., Collins, D., Allen, D., Clements, A., DenBleyker, A., Fraser, M., Jia, Y., McDonald-Buller, E., Michel, E., 2009. Air pollutant concentrations near three Texas roadways, Part I: ultrafine particles. Atmos. Environ. 43, 4513–4522.

This Page Intentionally Left Blank.

Appendix B

- Responses to Comments on the Environmental Notification Form

This Page Intentionally Left Blank.

Responses to MEPA Certificate on the Logan Airport Parking Project Environmental Notification Form

Table B-1 Responses to MEPA Certificate on the Logan Airport Parking Project Environmental Notification Form

Comment #	Author	Topic	Comment	Response
C.1	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	I expect that the DEIR will be a comprehensive and thorough filing that includes project plans for the Preferred Alternative and demonstrates that impacts have been avoided, minimized, and mitigated to the maximum extent feasible.	A primary goal of the Project is to reduce the adverse impacts of avoidable trips to and from Logan Airport. The added parking would have a range of environmental benefits and would create no long-term adverse environmental impacts; temporary construction impacts would be minimized and mitigated as detailed in Chapter 5, *Beneficial Measures/Mitigation*. The Draft Environmental Impact Report/ Environmental Assessment (DEIR/EA) reconfirms the benefits of reducing drop-off/pick-up trips on roadway congestion and emissions and provides a thorough description of the Project, including the latest site plans and elevations, and details anticipated project schedule and phasing. The DEIR/EA provides justification for the selection of the Preferred Alternative against evaluation criteria, with further description of the site selection, in Chapter 2, *Alternatives Analysis*. In identifying the Preferred Alternative, consideration was given to avoid, minimize, and mitigate environmental impacts to the maximum extent practicable.

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.2	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	The Scope for the DEIR requires additional information regarding project mitigation measures and methods to sustain and increase HOV mode share.	In addition to the overall Project benefits, mitigation measures are presented in Chapter 5, *Beneficial Measures/ Mitigation*, with construction period surface transportation mitigation measures presented in Section 5.2.3.2. No other transportation-related mitigation measures were required. Massport is exploring and implementing methods and policies to sustain and increase high-occupancy vehicle (HOV) mode shares to and from the Airport.
C.3	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	The DEIR should include site plans for existing and post-development conditions at a legible scale including the proposed garage structures and any curbside improvements and changes to the on-airport roadways.	Chapter 1, *Project Description/Purpose and Need* and Chapter 2, *Alternatives Analysis*, include diagrams that show the proposed garage in front of Terminal E that would be built on both sides of the existing pedestrian bridge between the Central Garage complex and Terminal E. These diagrams clearly show access and egress for automobiles and limousines along the Terminal E Arrivals Level roadway. Chapter 3, *Existing/Affected Environment* includes figures that depict existing conditions within the Project Areas. The DEIR/EA also presents graphics illustrating the new parking levels proposed at the Economy Garage. The Economy Garage expansion would rely on existing roadway infrastructure and signage.
C.4	Matthew A. Beaton, Secretary, EEA	Construction	The DEIR should provide additional information to address construction sequencing and phasing.	Chapter 2, *Alternatives Analysis* presents the anticipated construction schedule and phasing of the Proposed Project. Construction is planned to start with the new garage in front of Terminal E in Spring 2020 for an expected 2022 opening. Construction of the Economy Garage expansion is expected to begin in 2022 and open by the end of 2025.

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.5	Matthew A. Beaton, Secretary, EEA	Traffic, Pedestrians, and Other Circulation	The DEIR should address traffic volumes and crash rates at the Airport. It should include a description of existing and proposed conditions, including on and off-Airport access, on-Airport circulation, and parking.	Information about traffic volumes and crash rates at the Airport is provided in Chapter 3, *Existing/Affected Environment*, Section 3.3.1. The existing access, circulation, and parking conditions are also included in this section, while the proposed conditions are presented in Chapter 4, *Assessment of Impacts/ Environmental Consequences*, Section 4.5.1.
C.6	Matthew A. Beaton, Secretary, EEA	Traffic, Pedestrians, and Other Circulation	The project description should address pedestrian and transit connections between the garages and the airport; pedestrian, transit, and vehicular access and egress locations; access and revenue control systems; anticipated rate structures; and identify hybrid, alternative fuel, and EV parking locations.	Chapter 1, *Project Description/Purpose and Need* and Chapter 2, *Alternatives Analysis*, include diagrams that show garage access as well as ground-level pedestrian accommodations. Three pedestrian crosswalks would be provided between the garage and the outer curb at Terminal E. Connections to the pedestrian bridge between Terminal E and the Central Garage complex are also provided at this facility. The Economy Garage expansion would continue to be serviced by Massport's shuttle bus system. Pay-by-foot systems would encourage parkers to pay fees prior to returning to their vehicles via automated kiosks to enable the efficient flow of vehicles exiting the garages and reduce vehicle idling and associated air emissions. One percent of parking spaces would be preferred for low-emitting and fuel-efficient vehicles (e.g., hybrids) and additional 1 percent would be reserved for alternative fuel vehicles (e.g., electric, hydrogen); electric vehicle charging stations would accommodate 150 percent of demand in both proposed garages.
C.7	Matthew A. Beaton, Secretary, EEA	Electric Vehicles	As requested by MassDEP, it should include an evaluation of incorporating EV charging stations into the parking garages and identify the number and location of proposed stations. It should include a discussion of how the construction and design of the garage could facilitate future expansion of EV charging stations if warranted by demand.	As proposed, 20 electric vehicle charging stations would be initially be installed: 15 in the new garage in front of Terminal E and five in the Economy Garage. The locations of these stations will be determined as part of final design. Massport will continue to ensure that electric vehicle charging stations will accommodate 150 percent of demand.

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.8	Matthew A. Beaton, Secretary, EEA	Transportation Planning and Studies	As indicated above, the draft amended Parking Freeze regulations would require Massport to complete three studies to identify ways to further support alternative transit options to the Airport. The results of these studies can be used to inform and benefit the development of mitigation measures for the Logan Airport Parking Project. The DEIR should clarify the timeframe for completed studies relative to the timeframe for developing specific mitigation measures for the Logan Airport Parking Project which are identified in the ENF. It should identify any commitments that would be contingent on the completion of a study.	Massport is conducting the three MassDEP studies and the preliminary findings have been useful in informing this Proposed Project's planning. The Parking Project is one element of Massport's overall trip reduction strategy, targeting reduction of drop off/pick up trips. It is expected that the studies will be complete in late summer 2019.
C.9	Matthew A. Beaton, Secretary, EEA	Traffic, Pedestrians, and Other Circulation	The DEIR should address ground access considerations associated with the parking structures.	Ground access considerations are presented in Chapter 2, *Alternatives Analysis*, with specific options for access and egress presented in Sections 2.7.2 and 2.7.3. Chapter 4, *Assessment of Impacts/ Environmental Consequences* discusses the as-designed ground circulation at the proposed garages.
C.10	Matthew A. Beaton, Secretary, EEA	Traffic, Pedestrians, and Other Circulation	It should describe site and design constraints for both locations. It should identify how the Terminal E garage will be designed consistent with the curbside improvements and changes to on-airport runways associated with the Terminal E Modernization Project which will commence construction in 2018.	The curbside improvements reflect the four-lane improvements documented in the EA/EIR for the Terminal E Modernization Project. Construction of this Project will commence later in 2019. As part of the Terminal E Modernization Project, Terminal E curbsides were to be lengthened; however, as design of the new Terminal E curbs and the parking garage advanced, it was determined that the initial curb extension was no longer necessary. Massport regularly makes adjustments to curbs and on-Airport roadways to maximize safety and efficiency.
C.11	Matthew A. Beaton, Secretary, EEA	Regulations and Permitting	The DEIR should identify and describe any changes to the project since the filing of the ENF and provide an update on permitting. It should include a discussion of permitting requirements and document the project's consistency with regulatory standards, as appropriate.	Chapter 1, *Project Description/Purpose and Need* provides the changes to the Project since the Environmental Notification Form (ENF). The phasing of the Proposed Project would begin with the opening of the new garage in front of Terminal E in 2022 and the

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.11 (cont.)				Economy Garage expansion opening by the end of 2025. It also provides a list of anticipated permits along with their status.
C.12	Matthew A. Beaton, Secretary, EEA	Alternatives	The DEIR should expand on the initial alternatives analysis and summarize the findings of and the input provided by the community process that guided site selection. The DEIR should identify the number of parking spaces that could be accommodated at each of the alternative locations and describe in more detail why the Southwest Service Area location was eliminated from consideration.	Chapter 2, *Alternatives Analysis* summarizes and builds on the alternatives screening process described in the Project's ENF. This chapter also identifies how the new garage in front of Terminal E can accommodate 2,000 spaces and how this total fits with the construction phasing of the Terminal E Modernization Project and other terminal area construction and planning activities. Parking capacities at the other initial sites are also presented. The Southwest Service Area was not a preferred location by the Logan Impact Advisory Group (LIAG). Further, development of a parking facility in this location could preclude other future intermodal transportation options within the Airport boundary. Chapter 1, *Proposed Project/Purpose and Need*, Section 1.8 presents a summary of Massport's public involvement for the Proposed Project.
C.13	Matthew A. Beaton, Secretary, EEA	Construction	The DEIR should evaluate potential construction phasing and configurations.	Consideration is given to immediate parking needs and other ongoing projects at the Airport with respect to developing the proposed construction phasing and configurations. As documented in Chapter 1, *Project Description/Purpose and Need*, Massport anticipates the new garage in front of Terminal E to be operational in 2022 and the Economy Garage expansion operational by the end of 2025. The new garage in front of Terminal E would be constructed first in order to realize construction efficiencies with respect to other planned projects at the Airport, including the Terminal E Modernization Project - planned to begin later in 2019; provide operational flexibility in managing the parking supply; and to see passenger experience benefits sooner.

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.13 (cont.)				Additionally, ongoing and anticipated terminal area construction and planning activities will remove a number of commercial spaces, both in the short- and long-terms. This includes Massport's new plan to centralize transportation network company (TNC) operations (i.e., drop-offs and pick-ups) on the ground floor of the Central Garage complex, which would replace approximately 1,000 revenue-generating parking spaces. The new garage in front of Terminal E would compensate for these temporary losses. Massport would continue to be in full compliance with the Parking Freeze even when the out-of-service terminal area commercial parking spaces return to service.
C.14	Matthew A. Beaton, Secretary, EEA	Alternatives	It should compare and contrast benefits and potential impacts of alternatives in narrative form and in a tabular format.	Chapter 2, *Alternatives Analysis*, provides a narrative and tabular explanation of the advantages and disadvantages of each alternative - measured against a set of evaluation criteria that is consistent with the criteria detailed in the Project's ENF.
C.15	Matthew A. Beaton, Secretary, EEA	Parking Spaces Layout and Designations	The ENF indicates that the project will provide sufficient parking to accommodate approximately five years of peak-day parking demand if growth trends continue at current rates. The DEIR should identify the planning metrics and analysis used to determine the final number of proposed parking spaces (5,000 spaces).	The planning metric used to determine the proposed number of spaces is the number of days when the parking demand exceeds the striped on-Airport commercial revenue spaces. With anticipated growth in Airport passengers, an increase in the commercial parking supply of 5,000 spaces at Logan Airport would lower the number of days when parking demand exceeds commercial revenue parking to less than 10 days in 2022, a number similar to current conditions.
C.16	Matthew A. Beaton, Secretary, EEA	HOVs	The air quality analysis provided in the ENF is predicated on maintaining an approximately 30% HOV mode share and proportional growth in demand for HOV. The DEIR should demonstrate that the HOV programs and any proposed HOV improvement measures will provide the capacity to meet demand associated with growth.	Massport is committed to increasing the use of HOV ground transportation modes for passengers traveling to and from the Airport, with a new goal of 40 percent HOV by 2027. Massport will publish the results of the *2019 Logan Airport Air Passenger Ground-Access Survey*, showing the latest HOV mode share, and future surveys in the annual Logan Airport

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.16 (cont.)				Environmental Data Reports (EDRs) and Environmental Status and Planning Reports (ESPRs). Massport recently announced substantial improvements to the Logan Express bus service over the next two years, with a goal of doubling use of the service from 2-4 million annual riders. The Massport Board of Directors' recently approved ground transportation plan would expand and incentivize Logan Express by: 1) revitalizing Back Bay Logan Express service by moving it just outside the MBTA's Back Bay Station, 2) starting a new urban service from North Station, 3) improving services/amenities at existing suburban sites, 4) building parking capacity at existing sites including 3,000 spaces at the Framingham and Braintree locations, and 5) identifying new suburban locations. Further, as of May 1, 2019 passengers who take the Back Bay Logan Express service now get head-of-line priority in the security line when they arrive at Logan, and the drop-off fee for this service was reduced from $7.50 to $3.00 to the Airport and free from the Airport to downtown Boston. Section 3.3.1.2 in Chapter 3, *Existing/Affected Environment* includes more detailed information on Massport's ground access strategy and planned HOV investments.
C.17	Matthew A. Beaton, Secretary, EEA	HOVs	To support Massport's investments and extend their benefits, the DEIR should include an evaluation of measures to support HOV use and extend the associated air quality benefits of the program and identify to what extent these measures will contribute towards attaining the future mode share goal. These additional measures include: increasing the frequency of transit services, expansion of transit services, parking supply, and pricing; and implementation of tolls or charges that can be used to improve HOV measures. I	Massport has a long history of actively promoting transit, shared-ride, and other HOV modes to and from Logan Airport. As examples, Massport provides free, clean-fuel shuttle bus service for passengers and employees between the MBTA Blue Line Airport Station and all terminals and subsidizes the MBTA Silver Line (SL1) that provides free outbound Silver Line trips from the Airport; Massport has committed to pay for eight additional Silver Line buses (bringing the total to 16) to operate on the SL1 route by December 2024 (dependent on MBTA procurement). A full list of

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.17 (cont.)			note improvements to reduce idling time of HOV modes (i.e. Logan Express, Blue Line Airport Shuttle, and SL1 Silver Line) will also provide air quality benefits. I refer Massport to comment letters which recommend additional measures to improve HOV and reduce VMT.	Massport's key efforts are provided in Chapter 3, *Existing/Affected Environment*, Section 3.3.1.2 of the DEIR/EA. Massport recently announced substantial improvements to the Logan Express bus service to be implemented over the next two years, with a goal of doubling use of the service from 2-4 million annual riders. The Massport Board of Directors recently voted to approve a new ground transportation plan that would expand and incentivize Logan Express by: 1) revitalizing Back Bay Logan Express service by moving it just outside the MBTA's Back Bay Station, 2) starting a new urban service from North Station, 3) improving services/amenities at existing suburban sites, 4) building parking capacity at existing sites including 3,000 spaces at the Framingham and Braintree locations, and 5) identifying new suburban locations. Further, as of May 1, 2019 passengers who take the Back Bay Logan Express service now get head-of-line priority in the security line when they arrive at Logan, and the drop-off fee for this service was reduced from $7.50 to $3.00 to the Airport and free from the Airport to downtown Boston. With respect to TNC operations, the plan includes adding a $3.25 drop-off fee - effective October 1, 2019 - for TNC operations (the existing $3.25 pick-up fee will remain as is); incentivizing shared-ride customers with a discounted fee of $1.50; allowing TNC drop-offs at the terminal curb Arrivals Level from 4:00 to 10:00 AM; and requiring all TNC pick-ups at a new, dedicated central location on the ground floor of the Central Garage. These aspects of the plan are expected to reduce deadhead trips by as much as a third.
C.18	Matthew A. Beaton, Secretary, EEA	HOVs	I note monitoring and reporting on the progress towards achieving the goals and success of the mitigation program can be addressed in the Long-Term Parking Management Plan and future Environmental Status and Planning	Comment noted. Monitoring and reporting on the progress towards achieving the goals and success of the mitigation program will continue to be addressed in the Long-Term Parking Management Plan and future Environmental Status and Planning Report

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.18 (cont.)			Reports (ESPRs) and Environmental Data Reports (EDRs) (EEA#3247/5146).	(ESPR) and Environmental Data Reports (EDRs) filings.
C.19	Matthew A. Beaton, Secretary, EEA	Air Quality, Climate Change, and VMT Environmental Concerns	The DEIR should identify and analyze localized on-Airport, community ground access, and air quality conditions at each of the proposed locations. The updated air quality analysis for existing and future year conditions should evaluate the changes in transportation and air quality emissions. The air quality analysis provided in the ENF should be revised to reflect the proposed construction phasing and timeframe to identify when the air quality benefits associated with reduced VMT will be realized.	Chapter 4, *Assessment of Impacts/ Environmental Consequences* updates the community ground access and air quality analyses. With the Proposed Project, total emissions of volatile organic compounds (VOC) and nitrogen oxides (NO_x) would decrease when compared to the No-Build Alternative. These reductions range from 11 to 12 percent depending on the pollutant. These benefits would be achieved in stages, correlating to the availability of additional parking. A portion of these emissions reductions would be realized when the new garage in front of Terminal E is operational in 2022. Similar reductions would be expected until the Economy Garage expansion is operational by the end of 2025, at which point all additional spaces would be built and the full reduction in regional vehicle miles traveled (VMT) and emissions associated with the "would-be parkers" would occur. The microscale evaluation presented in Chapter 4, *Assessment of Impacts/ Environmental Consequences*, Section 4.5.2.4 demonstrates that the development of the Proposed Project would not result in adverse localized air quality impacts. The queueing projected at proximate intersections and the Terminal E curbside are not expected to increase carbon monoxide (CO) concentrations beyond the National Ambient Air Quality Standards (NAAQS).
C.20	Matthew A. Beaton, Secretary, EEA	Air Quality, Climate Change, and VMT Environmental Concerns	The DEIR should include an analysis of GHG emissions and mitigation measures in accordance with the standard requirements of the MEPA GHG Policy and Protocol. The analysis should include project-related stationary source emissions (exterior/interior parking structure lighting, ventilation, etc.) and	An analysis of greenhouse gas emissions and mitigation measures in accordance with the standard requirements of the MEPA Greenhouse Gas Policy and Protocol has been conducted and the results included in this DEIR/EA. The analysis shows that the Proposed Project would mitigate 382 tons per year (tpy) of

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.20 (cont.)			mobile source emissions (passenger vehicles).	stationary source CO_2 emissions and 1,812 tpy of mobile source CO_2 emissions. The new solar photovoltaic installation at the new garage in front of Terminal E would offset an additional 89 tpy of CO_2, while the existing solar photovoltaic panel-structures atop the Economy Garage would be relocated to the new top level of the garage and continue to offset about 28 tpy of CO_2. The results of this analysis are provided in in Chapter 4, *Assessment of Impacts/ Environmental Consequences*, Section 4.5.4.2.
C.21	Matthew A. Beaton, Secretary, EEA	Building Energy Use	The DEIR should present an evaluation of mitigation measures as outlined in the comments from the Department of Energy Resources (DOER) as appropriate based on whether the parking structures will contain conditioned spaces.	Both garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths. Heat pumps or electrical heaters would be used to condition these spaces - assumed under both the base case and proposed design. Additionally, a new staff restroom in the new garage in front of Terminal E would require mechanical ventilation but would not otherwise be conditioned. These demand loads are included in the greenhouse gas emissions analysis, which is provided in in Chapter 4, *Assessment of Impacts/Environmental Consequences*, Section 4.5.4.2.
C.22	Matthew A. Beaton, Secretary, EEA	Building Energy Use	I note that DOER' s comments also identify mitigation measures that should be explored absent conditioned space, including but not limited to reduced lighting power densities (LPD) for interior and exterior lighting, parking structure ventilation, and solar photovoltaic (PV) installations. At a minimum, I expect the DEIR will present an evaluation of the feasibility and impact of these measures. This evaluation can be performed as separate calculations in lieu of energy modeling.	The Proposed Project lowers lighting power densities compared to the minimum high standards required by the International Energy Conservation Code (IECC) 2015. Such efficiencies are estimated to save 690,843 kWh at the new garage in front of Terminal E and 384,870 kWh at the Economy Garage expansion annually. Both garages would be designed for natural ventilation and not include a significant amount of conditioned spaces. Solar photovoltaic systems at the new garage in front of Terminal E would

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.22 (cont.)				produce an estimated 250,000 kWh per year - enough to offset approximately 60 percent of electricity consumption associated with the garage interior lighting or about 15 percent of total facility electrical consumption. The existing Economy Garage solar photovoltaic system produces approximately 77,800 kWh per year on average. More information can be found in Chapter 4, *Assessment of Impacts/Environmental Consequences*, Sections 4.5.3.2 and 4.5.4.2.
C.23	Matthew A. Beaton, Secretary, EEA	Air Quality, Climate Change, and VMT Environmental Concerns	The DEIR should include an evaluation of rooftop or carport solar PV. It should include a cost analysis to determine the financial feasibility of solar (including potential payback periods) and propose an installation that can be supported by the maximum available roof area (excluding areas dedicated for mech. equipment) on both parking structures. The DEIR should include the assumed panel efficiency, estimate the electrical output of the system, and estimate annual GHG reductions due to the use of renewable energy instead of electricity or natural gas. The analysis should include a narrative and data to support the Proponent's adoption (or dismissal) of solar PV.	Solar photovoltaic systems at the new garage in front of Terminal E would produce an estimated 250,000 kWH per year assuming a panel efficiency of approximately 15 percent. This would be a system of canopy structure design (i.e., carport) and cover approximately 10,000 SF of the roof area. The existing Economy Garage solar photovoltaic system produces approximately 77,800 kWh per year on average and would be relocated to the facility's new highest level upon completion of construction. The incorporation of on-site solar photovoltaic systems is consistent with Massport's sustainability program and its Sustainable and Resilient Design Standards and Guidelines and was an expected design feature from initial project planning. Accordingly, no financial feasibility assessments (including potential payback periods) were performed. Massport is not eligible for any federal incentives or incentives available through the Solar Massachusetts Renewable Target (SMART) Program. The new solar photovoltaic array at the new garage in front of Terminal E is estimated to cost $1.52 million. More information can be found in Chapter 4, *Assessment of Impacts/ Environmental Consequences*, Section 4.5.4.2.

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.24	Matthew A. Beaton, Secretary, EEA	Air Quality, Climate Change, and VMT Environmental Concerns	The GHG analysis should include an evaluation of the potential GHG emissions of the project's mobile emissions sources using the EPA MOVES emissions model. The DEIR should use data gathered as part of the air quality analysis to determine mobile emissions for Existing Conditions, and the future No-Build, Build, and Build with Mitigation Conditions. The Build with Mitigation Conditions should incorporate measures and associated reductions identified in the Air Quality section above that will support HOV use and extend the associated air quality benefits of the program.	With the Proposed Project, total greenhouse gas emissions would decrease when compared to the No-Build Alternative. The estimated savings are 1,812 tons per year or 12 percent. As the Build Alternative is anticipated to reduce regional pollutant emissions, a Build-with-Mitigation scenario is not required under the MEPA Greenhouse Gas Emissions Policy and Protocol. The U.S. Environmental Protection Agency's (EPA's) MOVES - Motor Vehicle Emissions Simulator, vMOVES2014b was utilized for this analysis.
C.25	Matthew A. Beaton, Secretary, EEA	Air Quality, Climate Change, and VMT Environmental Concerns	The DEIR should provide emission tables that compare base case emissions in tons per year (tpy) with the Preferred Alternative showing the anticipated reduction in tpy and percentage by emissions source (direct, indirect and transportation).	Chapter 4, *Assessment of Impacts/ Environmental Consequences*, Section 4.5.4.2 details the anticipated greenhouse gas emissions for the Proposed Project. The Proposed Project would reduce CO_2 emissions from stationary sources by 382 tons per year (tpy) or 28.6 percent compared to a base case scenario. Compared to the No-Build Alternative, the Proposed Project would mitigate 1,812 tpy of CO_2 or 12 percent. The new solar photovoltaic installation at the new garage in front of Terminal E would offset an additional 89 tpy of CO_2 emissions, while the existing solar photovoltaic panel-structures on the Economy Garage would be relocated to the new top level of the garage and continue to offset about 28 tpy of CO_2.
C.26	Matthew A. Beaton, Secretary, EEA	Building Energy Use	If the garages include conditioned space, information should be provided for each building in a format similar to the example table provided in DOER's comment letter.	The new garage spaces would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths. Information on energy use at the proposed garages is provided in Chapter 4, *Assessment of Impacts/Environmental Consequences*, Section 4.5.3.2.

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.27	Matthew A. Beaton, Secretary, EEA	Water	The project is in the conceptual design stage and, as such, provides meaningful opportunities for incorporation of sustainability measures. The DEIR should describe the project's consistency with Massport's Floodproofing Design Guide to demonstrate that the project will incorporate measures into the structure and site design to address potential impacts related to predicted sea level rise.	Coordination has been conducted with Massport's Climate Mitigation & Resiliency group in the planning of the Proposed Project. All critical infrastructure will be elevated above the applicable design flood elevation as identified in Massport's Floodproofing Design Guide. Please refer to Chapter 4, *Assessment of Impacts/Environmental Consequences*, Section 4.5.4.2, for more information.
C.28	Matthew A. Beaton, Secretary, EEA	Local Impacts and Mitigation	The ENF indicates that constructing additional levels on the Economy Garage can serve as an additional noise barrier to the adjacent neighborhood. The DEIR should identify how the sound barrier benefits of the taller garage have been maximized through its design. This evaluation should account for the expanded Terminal E building.	The Proposed Project would not change any airfield or aircraft ground operations. Noise from aircraft ground operations with the Economy Garage expansion would generally be 1 to 3 dB lower northwest and north of the Economy Garage due to the screening of the additional floors on the Economy Garage. Aircraft ground operations noise would typically increase at receivers west of the Economy Garage due to sound that could be reflected off the taller portion of the facility; however, such increases would be imperceptible (0.1 to 0.4 dB) and are well below the Federal Aviation Administration criterion for a significant impact. The Economy Garage expansion mimics the design of the existing facility. More detail on this analysis is presented in Section 4.5.5.3 of Chapter 4, *Assessment of Impacts/Environmental Consequences*.
C.29	Matthew A. Beaton, Secretary, EEA	Construction	The DEIR should identify construction period impacts, including noise, air quality, traffic, solid and hazardous waste, and water quality, and identify avoidance, minimization, and mitigation measures.	This DEIR/EA documents the anticipated temporary construction period impacts across applicable environmental resource categories in Chapter 4, *Assessment of Impacts/Environmental Consequences*. As needed mitigation measures are documented in Chapter 5, *Beneficial Measures/Mitigation*.
C.30	Matthew A. Beaton, Secretary, EEA	Construction	The DEIR should describe the project phasing and sequencing and address how construction will occur to avoid impacting the existing constrained parking supply.	Massport would construct approximately 2,000 spaces in the new garage in front of Terminal E first, followed by approximately 3,000 spaces at the existing Economy Garage. The new

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.30 (cont.)				garage in front of Terminal E would open in 2022, while the Economy Garage expansion would be operational by the end of 2025. Chapter 1, *Project Description/Purpose and Need*, Section 1.5.1, Project Phasing and Costs details the sequencing of construction by phase. Temporary construction period impacts are documented in Chapter 4, *Assessment of Impacts/Environmental Consequences*. Mitigation measures associated with construction impacts are documented in Chapter 5, *Beneficial Measures/Mitigation*. Massport typically works closely with its Ground Transportation Unit and the selected contractor to minimize construction-related impacts to commercial parking.
C.31	Matthew A. Beaton, Secretary, EEA	Construction	It should address construction phasing and whether construction will occur simultaneously with the Terminal E project.	Consideration is given to immediate parking needs and other ongoing projects at the Airport with respect to developing the proposed construction phasing and configurations. As documented in Chapter 1, *Project Description/Purpose and Need*, and Chapter 2, *Alternatives Analysis*, providing parking availability in the new garage in front of Terminal E first serves an immediate need, enhances passenger convenience and also fits within the construction schedule for the Terminal E Modernization Project, which is planned to begin later in 2019. Once the first garage is complete and operational, construction of the Economy Garage expansion would commence in 2022 and is planned to be complete by the end of 2025.
C.32	Matthew A. Beaton, Secretary, EEA	Regulations and Permitting	The DEIR should include a separate chapter summarizing proposed mitigation measures. This chapter should also include draft Section 61 Findings for each area of impact associated with Massport's Preferred Alternative.	The Proposed Project would have a range of environmental benefits and would create no long-term adverse environmental impacts. Proposed mitigation measures for anticipated temporary construction impacts are discussed and summarized in a separate chapter, Chapter 5, *Beneficial Measures/Mitigation*. Draft Section 61 findings are documented in Appendix C.

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.33	Matthew A. Beaton, Secretary, EEA	Regulations and Permitting	The DEIR should contain clear commitments to implement these mitigation measures, estimate the individual costs of each proposed measure, identify the parties responsible for implementation (either funding design and construction or performing actual construction), and a schedule for implementation.	The Proposed Project would have a range of environmental benefits and would create no long-term adverse environmental impacts. Proposed mitigation measures for anticipated temporary construction impacts are discussed and summarized in a separate chapter, Chapter 5, *Beneficial Measures/Mitigation*. These measures would be implemented during the construction period for the Proposed Project; their costs are built into the overall program costs detailed in Chapter 1, *Project Description/Purpose and Need*.
C.34	Matthew A. Beaton, Secretary, EEA	Air Quality, Climate Change, and VMT Environmental Concerns	To ensure that all GHG emissions reduction measures adopted by the Proponent in the Preferred Alternative arc actually constructed or performed by the Proponent, I require Proponents to provide a self-certification to the MEPA Office indicating that all of the required mitigation measures, or their equivalent, have been completed. The commitment to provide this self-certification in the manner outlined above should be incorporated into the draft Section 61 Findings included in the DEIR.	Massport will provide self-certification to the MEPA Office indicating that all required mitigation measures, or their equivalents, have been completed. This commitment has been incorporated into the Draft Section 61 Findings included as Appendix C. Documentation will be reported on and included in the EDR/ESPR filings.
C.35	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	The DEIR should contain a copy of this Certificate and a copy of each comment letter received on the ENF.	A copy of the Secretary's Certificate and the comment letters received on the Project's ENF is attached to the DEIR/EA as Appendix A.
C.36	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	In order to ensure that the issues raised by commenters are addressed, the DEIR should include direct responses to these comments to the extent that they are within MEPA jurisdiction. This directive is not intended, and shall not be construed, to enlarge the scope of the EIR beyond what has been expressly identified in this Certificate. The response can refer to future EDRs and/or ESPRs to address issues that are not within the DEIR Scope.	A copy of the Secretary's Certificate and the comment letters received on the Project's ENF is attached to the DEIR/EA as Appendix A. Direct narrative responses are provided in Appendix B. Where applicable, comment responses refer to the EDRs and ESPRs.
C.37	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	I recommend that Massport employ an indexed response to comments format,	A copy of the Secretary's Certificate and the comment letters received on the Project's ENF is attached to the DEIR/EA

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.37 (cont.)			supplemented as appropriate with direct narrative response.	as Appendix A. Direct narrative responses are provided in Appendix B. Comment responses are numbered and organized by subject matter and comment author.
C.38	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	In accordance with Section 11.16 of the MEPA Regulations and as modified by this Certificate, Massport should circulate a hard copy of the DEIR to each State and City Agency from which the Proponent will seek permits.	Massport will circulate hard copies of the DEIR/EA to each agency from which permits will be sought.
C.39	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	Massport must circulate a copy of the DEIR to all other parties that submitted individual written comments. Per 30 l CMR 11.16(5), the Proponent may circulate copies of the DEIR to these other parties in CD-ROM format or by directing commenters to a project website address.	The DEIR/EA will be made available to all commenters on the Project's ENF through Massport's website (www.massport.com) or electronically on CD. Persons may request limited CD or printed copies of the DEIR/EA from Stewart Dalzell, telephone (617) 568-3524, email: sdalzell@massport.com. Electronic and printed copies of the DEIR/EA will also be available for review at local public libraries including the Boston Public Library's Main Branch, Charlestown Branch, and East Boston Branch, in addition to the Chelsea Public Library, Revere Public Library, and Winthrop Public Library.
C.40	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	However, Massport should make available a reasonable number of hard copies to accommodate those without convenient access to a computer and distribute these upon request on a first-come, first-served basis. Massport should send correspondence accompanying the CD-ROM or website address indicating that hard copies are available upon request, noting relevant comment deadlines, and appropriate addresses for submission of comments.	The DEIR/EA will be made available to all commenters on the Project's ENF through Massport's website (www.massport.com) or electronically on CD. Persons may request limited CD or printed copies of the DEIR/EA from Stewart Dalzell, telephone (617) 568-3524, email: sdalzell@massport.com. Electronic and printed copies of the DEIR/EA will also be available for review at local public libraries including the Boston Public Library's Main Branch, Charlestown Branch, and East Boston Branch, in addition to the Chelsea Public Library, Revere Public Library, and Winthrop Public Library. Massport will ensure that correspondence accompanying the website address or

Table B-1 Responses to Secretary Certificate on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
C.40 (cont.)				CD-ROM indicates that hard copies are available upon request. Relevant comment deadlines and appropriate addresses for submission of comments will be included in this correspondence.
C.41	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	A CD-ROM copy of the filing should also be provided to the MEPA Office.	A CD-ROM copy of the DEIR/EA filing will be provided to the MEPA Office.
C.42	Matthew A. Beaton, Secretary, EEA	DEIR Formatting, Content, and Process	A copy of the EIR should be made available for review at the following Libraries: Boston Public Library - Main, Orient Heights, and East Boson Branches, Chelsea Public Library, Winthrop Public Library, and Revere Public Library	Electronic and printed copies of the DEIR/EA will also be available for review at local public libraries including the Boston Public Library's Main Branch, Charlestown Branch, and East Boston Branch, in addition to the Chelsea Public Library, Revere Public Library, and Winthrop Public Library.

Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form

Comment #	Author	Topic	Comment	Response
1-1	Beth Card, Deputy Commissioner, Policy and Planning (MassDEP)	Electric Vehicles	"The installation of electric vehicle charging stations should be included in the parking garages for a minimum percentage of parking spaces and additional electrical wiring should be added to ensure additional spaces are “make ready” to accommodate additional electric vehicles as the percentage of vehicles in the fleets increases over time. The electrification of the transportation system is a key part of the Commonwealth’s plan to achieve greenhouse gas reduction goals under the Global Warming Solutions Act.	As proposed, 20 electric vehicle charging stations would be initially be installed: 15 in the new garage in front of Terminal E and five in the Economy Garage. The locations of these stations will be determined as part of final design. Massport will continue to ensure that the number of electric vehicle charging stations will accommodate 150 percent of demand for the new spaces on an ongoing basis.
1-2	Beth Card, Deputy Commissioner, Policy and Planning (MassDEP)	Parking Spaces Layout and Designations	The parking garages should include the designation of preferred parking spaces for battery electric vehicles, plug-in hybrid electric vehicles, and hydrogen fuel cell vehicles as an additional incentive to promote these vehicles.	"The current plan is to reserve 20 spaces in the new garage in front of Terminal E and 30 spaces in the Economy Garage expansion for low-emitting and fuel-efficient vehicles (e.g., hybrids). An additional 20 spaces in the new garage in front of Terminal E and 30 spaces in the Economy Garage expansion would be reserved for alternative fuel vehicles (e.g., electric, hydrogen). Additionally, the number of electric vehicle charging stations would accommodate 150 percent of demand for the new spaces on an ongoing basis.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
1-3	Beth Card, Deputy Commissioner, Policy and Planning (MassDEP)	Construction	Massport should use construction equipment with engines manufactured to Tier 4 federal emission standards, which are the most stringent emission standards currently available for off-road engines. If a piece of equipment is not available in the Tier 4 configuration, then Massport should use construction equipment that has been retrofitted with the best available after-engine emission control technology, such as diesel oxidation catalysts (DOCs) or diesel particulate filters (DPFs), to reduce exhaust emissions during the construction period of the project.	To mitigate construction period air quality emissions from construction equipment, Massport will require all contractors to comply with guidelines that relate to construction vehicle/equipment anti-idling and retrofitting of appropriate diesel construction equipment with diesel oxidation catalysts and/or particulate filters. Additionally, to the extent practicable, Massport will reduce on-site construction vehicle speeds and use low- or zero-emission equipment.
1-4	Beth Card, Deputy Commissioner, Policy and Planning (MassDEP)	Construction	Massport should ensure that construction activities do not cause or contribute to a condition of air pollution due to dust, odor or noise pursuant to 310 CMR 7.09 Dust, Odor, Construction, and Demolition, and 310 CMR 7.10 Noise.	The Proposed Project will include construction-period avoidance, minimization, and mitigation measures with respect to air quality and noise pursuant to 310 CMR 7.09 Dust, Odor, Construction, and Demolition and 310 CMR 7.10, Noise. Analyses of air quality and noise associated with the construction of the Proposed Project are provided in Section 4.5.2.6 and Section 4.5.5.5 of Chapter 4, *Assessment of Impacts/ Environmental Consequences*. Chapter 5, *Beneficial Measures/ Mitigation* outlines the mitigation measures planned for the Proposed Project's temporary construction-period impacts.
1-5	Beth Card, Deputy Commissioner, Policy and Planning (MassDEP)	Construction	Massport should identify plans to prohibit excessive idling during the construction period (e.g., driver training, periodic inspections by site supervisors, and posting signage) to ensure compliance with vehicle idling regulation (310 CMR 7.11) that prohibit motor vehicles from idling their engines more than five minutes unless the idling is necessary to service the vehicle or to operate engine-assisted power equipment.	Massport aggressively enforces the Commonwealth's anti-idling regulations.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
1-6	Beth Card, Deputy Commissioner, Policy and Planning (MassDEP)	HOVs	To sustain air quality benefits Massport should evaluate and implement measures to increase HOV and transit travel modes to the airport, including expanding Logan Express bus service, increasing Silver Line service to the airport, and providing incentives to increase HOV use.	Massport agrees and has prioritized advancing high-occupancy vehicle (HOV) programs to increase their use by passengers and employees. A summary of the recent and pending HOV initiatives is provided in Chapter 3, *Existing/Affected Environment,* Section 3.3.1.2 Massport has developed a robust program to address transportation network company (TNC) and HOV goals. Massport plans to double Logan Express ridership to 4 million passengers by improving Back Bay Logan Express service, starting a new urban Logan Express from North Station, enhancing services and amenities at existing suburban Logan Express sites (including increasing bus frequencies), planning for and increasing parking capacity at existing sites, and identifying new suburban Logan Express locations.
2-1	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Air Quality, Climate Change, and VMT Environmental Concerns	Future submissions should demonstrate that the project is taking all feasible measures to avoid, minimize and mitigate GHG emissions. The GHG Policy and supporting documentation is available at http://www.mass.gov/eea/agencies/mepa/greenhouse-gas-emissions-policy-and-protocol-generic.html	An analysis of greenhouse gas emissions and mitigation measures in accordance with the standard requirements of the MEPA Greenhouse Gas Policy and Protocol has been conducted and the results included in this Draft Environmental Impact Report/ Environmental Assessment (DEIR/EA). The analysis shows that the Proposed Project would mitigate 382 tons per year (tpy) of stationary source carbon dioxide (CO_2) emissions and 1,812 tpy of mobile source CO_2 emissions. The new solar photovoltaic installation at the new garage in front of Terminal E would offset an additional 89 tpy of CO_2, while the existing solar photovoltaic panel-structures at the Economy Garage would be relocated to the new top level of the garage and continue to offset about 28 tpy of CO_2. The results of this analysis are provided in in Chapter 4,

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
2-1 (cont.)				*Assessment of Impacts/Environmental Consequences*, Section 4.5.4.2.
2-2	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Air Quality, Climate Change, and VMT Environmental Concerns	Above-code mitigation measures and renewables should be thoroughly evaluated to maximize all feasible GHG avoidance, including: PV: Solar PV could have a significant positive effect on GHG reduction for this project.	The Project lowers lighting power densities compared to the minimum high standards required by the International Energy Conservation Code (IECC) 2015. Such efficiencies are annually estimated to save 690,843 kWh at the new garage in front of Terminal E and 384,870 kWh at the Economy Garage expansion. All new spaces would be designed for natural ventilation and only include a limited amount of conditioned spaces. Solar photovoltaic systems at the new garage in front of Terminal E would produce an estimated 250,000 kWh per year - enough to offset approximately 60 percent of electricity consumption associated with the garage interior lighting or about 15 percent of total facility electrical consumption. The existing Economy Garage solar photovoltaic system produces approximately 77,800 kWh per year on average. More information can be found in Chapter 4, *Assessment of Impacts/Environmental Consequences*, Sections 4.5.3.2 and 4.5.4.2.
2-3	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	Envelope: We recommend at least two above-code envelope mitigation measures be evaluated. Be sure to consider the value of downsizing HVAC systems as envelope improves. (Only include if conditioned space is proposed.)	The proposed parking garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths. Heat pumps or electrical heaters would be used to condition these spaces - assumed under both the base case and proposed design. Additionally, a new staff restroom at the new garage in front of Terminal E would require mechanical ventilation, but would not otherwise be conditioned.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
2-3 (cont.)				These demand loads are included in the greenhouse gas emissions analysis for stationary sources, the results of which are provided in in Chapter 4, *Assessment of Impacts/Environmental Consequences*, Section 4.5.4.2.
2-4	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	Heat Pump: Heat pumps may be an effective strategy, providing highly efficient cooling and heating while also enabling trading of concurrent heating and cooling. We recommend both space and water-heating heat pumps be evaluated. (Only include if conditioned space is proposed.)	The proposed garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths. Heat pumps or electrical heaters would be used to condition these spaces - assumed under both the base case and proposed design. The hot water demand at both facilities will be limited to small staff spaces; however, Massport will investigate opportunities to heat it via heat pumps.
2-5	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	Variable Refrigerant Flow: We recommend an evaluation of VRF, which also provide highly-efficient cooling and heating as well as trading of concurrent heating and cooling. (Only include if conditioned space is proposed.)	Massport will consider Variable Refrigerant Flow (VRF) in HVAC system designs, where appropriate.
2-6	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	Building/Garage Lighting: We recommend a thorough examination of reduced lighting power densities for both interior and exterior lighting.	The Proposed Project lowers lighting power densities for both interior and exterior lighting compared to the minimum high standards required by the International Energy Conservation Code (IECC) 2015. For example, interior parking level lighting would be reduced from 0.19 watts per square foot to a maximum of 0.09 watts per square foot. Lighting efficiencies are estimated to save 690,843 kWh at the new garage in front of Terminal E and 384,870 kWh at the Economy Garage expansion annually.
2-7	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	Energy Recovery; High Efficiency Equipment: Where not already required by code, we recommend energy recovery options be investigated. Above code heating,	HVAC system designs will place a priority on the use of high efficiency equipment. The amount of conditioned spaces in both garages are a very small percentage of the project; therefore, the

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
2-7 (cont.)			cooling, pumping, fan and appliances also typically provide effective GHG reduction approaches. (Only include if conditioned space is proposed.	opportunity to utilize energy recovery is limited.
2-8	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	Responsive Systems and Controls: Responsive HVAC systems, where not already required by Code, such as economizers and demand-controlled ventilation usually are effective GHG mitigation strategies which we recommend be investigated (Only include if conditioned space is proposed.)	HVAC system designs will place a priority on the use of high efficiency equipment. The amount of conditioned spaces in both garages are a very small percentage of the project; therefore, the opportunity to utilize responsive system controls is limited.
2-9	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	We recommend a thorough evaluation be conducted on financial benefits associated with efficiency and renewables.	Solar photovoltaic systems at the new garage in front of Terminal E would produce an estimated 250,000 kWh per year assuming a panel efficiency of approximately 15 percent - enough to offset approximately 60 percent of electricity consumption associated with the garage interior lighting or about 15 percent of total facility electrical consumption. This would be a system of canopy structure design (i.e. carport) and cover approximately 10,000 SF of the roof area. The existing Economy Garage solar photovoltaic system produces approximately 77,800 kWh per year on average and would be relocated to the facility's new highest level upon completion of construction. The incorporation of on-site solar photovoltaic systems in the Proposed Project is consistent with Massport’s sustainability program and its Sustainable and Resilient Design Standards and Guidelines, and was an expected design feature from initial project planning. Accordingly, no financial feasibility assessments (including potential payback periods) were performed. Massport is not eligible for any federal incentives or incentives available through the Solar Massachusetts Renewable Target (SMART) Program. The new solar photovoltaic array at the new garage in front of Terminal E is

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
2-9 (cont.)				estimated to cost $1.52 million. More information, including estimated GHG emissions offsets, can be found in Chapter 4, *Assessment of Impacts/ Environmental Consequences*, Section 4.5.4.2.
2-10	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	In order to expedite the DOER review, we recommend the following accompany the submission: A table similar to the example below should be included. Table may be simplified to only lighting and ventilation if the project does not include conditioned space.	The proposed parking garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths that comprise less than 2 percent of the overall Project Areas. Chapter 4, *Assessment of Impacts/ Environmental Consequences*, Section 4.5.3.2 details the expected energy savings from lower lighting power densities in both garages.
2-11	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	A description of the proposed building envelope assembly: report both component R-values and whole assembly U-factor. Utilize the pre-calculated relationships between R-Value and U-factor contained in Appendix A in the code. (Only include if conditioned space is proposed.)	The proposed parking garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths that comprise less than 2 percent of the overall Project Areas. Due to this minimal contribution, this is not planned to be submitted as part of the DEIR/EA.
2-12	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	A description of the building energy simulation model and procedures utilized. (Only include if conditioned space is proposed.)	The proposed parking garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths that comprise less than 2 percent of the overall Project Areas. Due to this minimal contribution, this is not planned to be submitted as part of the DEIR/EA. Appendix F, *Air Quality/Emissions Reduction Technical Appendix* includes the inputs to the Proposed Project's energy load calculations.
2-13	Paul F. Ormand, P.E., Energy	Building Energy Use	A detailed and complete table of modeling inputs showing the item and the input value for both the base and	The proposed parking garages would be designed for natural ventilation and not include a significant amount of

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
2-13 (cont.)	Efficiency Engineer, Mass DOER		as-designed scenarios. The area of the building should be included.(Only include if conditioned space is proposed.)	conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths that comprise less than 2 percent of the overall Project Areas. Appendix F, *Air Quality/Emissions Reduction Technical Appendix* includes the inputs to the Proposed Project's energy load calculations.
2-14	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	The output of the model showing the monthly and annual energy consumption, totalized and by major end use system. (Only include if conditioned space is proposed.)	The proposed parking garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths that comprise less than 2 percent of the overall Project Areas. Appendix F, *Air Quality/Emissions Reduction Technical Appendix* includes the inputs to the Proposed Project's energy load calculations. Only annual energy consumption by major end use system is provided.
2-15	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	Baseline (e.g. Code) energy use intensity and proposed mitigated building energy use intensity. (Only include if conditioned space is proposed.)	The proposed parking garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths that comprise less than 2 percent of the overall Project Areas. Appendix F, *Air Quality/Emissions Reduction Technical Appendix* includes the inputs to the Proposed Project's energy load calculations.
2-16	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	Project modeling files are to be submitted to the DOER with the submittal on a flash drive or may be transmitted via electronic file transfer to paul.ormond@massmail.state.ma.us. (Only include if conditioned space is proposed.)	The proposed parking garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths that comprise less than 2 percent of the

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
2-16 (cont.)				overall Project Areas. Due to this minimal contribution, this is not planned to be submitted as part of the DEIR. Appendix F, *Air Quality/Emissions Reduction Technical Appendix* includes the inputs to the Proposed Project's energy load calculations.
2-17	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	Separate "side calcs" may be required for non-building energy consuming site improvements which are not included in the building energy modeling software (e.g. parking lot lighting).	Appendix F, *Air Quality/Emissions Reduction Technical Appendix* includes the inputs to the Proposed Project's energy load calculations. These include building-based energy loads. The Project Areas currently have site lighting vaults that would provide any necessary energy for site lighting.
2-18	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Air Quality, Climate Change, and VMT Environmental Concerns	Estimate area of roof potentially usable for solar development (e.g. 'Usable Roof Area" (URA)). Estimate resulting power production and associated GHG reduction if all this URA was utilized.	Solar photovoltaic systems at the new garage in front of Terminal E would produce an estimated 250,000 kWh per year assuming a panel efficiency of approximately 15 percent - enough to offset approximately 60 percent of electricity consumption associated with the garage interior lighting or about 15 percent of total facility electrical consumption. This would be a system of canopy structure design (i.e. carport) and cover approximately 10,000 SF of the roof area. This size of this solar system with respect to the available roof area was planned to accommodate other ongoing projects, including the potential for an automated people mover project. The existing solar photovoltaic system at the Economy Garage would be relocated to the new highest level upon completion of construction. This system produces approximately 77,800 kWh per year on average. The solar photovoltaic installation at the new Garage at Terminal E would offset an additional 89 tpy of CO_2 emissions, while the existing solar photovoltaic panel-structures at the Economy Garage would continue to offset about 28 tpy of CO_2 emissions.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
2-19	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	A description of the proposed project building usage and size, including a site plan and elevation views, should be included.	Chapter 1, *Project Description/Purpose and Need* describes the proposed garages and includes site plans and elevations. Chapter 2, *Alternatives Analysis* provides additional information.
2-20	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	Provide a summary of discussions with MassSave. (Only include if conditioned space is proposed.)	The proposed parking garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths that comprise less than 2 percent of the overall Project Areas. Due to this minimal contribution, this is not planned to be submitted as part of the DEIR/EA.
2-21	Paul F. Ormand, P.E., Energy Efficiency Engineer, Mass DOER	Building Energy Use	We recommend cross-examining produced model results' total and individual end uses with representative, prototype buildings developed by Pacific Northwest National Labs/Department of Energy found here: (Only include if conditioned space is proposed.)	The proposed parking garages would be designed for natural ventilation and not include a significant amount of conditioned spaces other than mechanical/electrical rooms, elevator lobbies, and cashier booths that comprise less than 2 percent of the overall Project Areas. Due to this minimal contribution, this is not planned to be submitted as part of the DEIR/EA.
3-1	Marc D. Draisen, Executive Director, MAPC	HOVs	Nevertheless, MAPC has concerns that the proposed increase in commercial parking spaces may inadvertently cause people who customarily use transit, shared-rides, and other HOV modes to access Logan Airport by single occupant vehicle (SOV) instead.	As shown in the Project's Environmental Notification Form (ENF) and our Environmental Data Report/ Environmental Status and Planning Report (EDR/ESPR) filings, parking is one element of our ground access strategy at the Airport. Massport continues to support and expand our HOV programs and our partnerships with the Massachusetts Bay Transportation Authority (MBTA) and private transit carriers.
3-2	Marc D. Draisen, Executive Director, MAPC	HOVs	It is paramount that Massport continue to support strategies to enhance transit, shared-rides and HOV as ways to reduce SOV trips. Simply allowing for an increase in parking spaces could have the inadvertent consequence of undermining these non-SOV alternatives.	As outlined in the ENF and our annual EDR/ESPR filings, parking is one element of Massport's ground access strategy at Logan Airport. Massport continues to support and expand our HOV programs including Logan Express, and our partnerships with MBTA and private transit carriers.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
3-3	Marc D. Draisen, Executive Director, MAPC	Air Quality, Climate Change, and VMT Environmental Concerns	MAPC applauds Massport for proposing to undertake three studies intended to aid their long-range efforts to address VMT and air quality impacts of different ground access modes for travel to and from Logan Airport, but we believe it is essential that Massport first conduct these studies and then implement their recommendations before increasing the number of commercial parking spaces.	Massport is conducting the three Massachusetts Department of Environmental Protection (MassDEP) studies and the preliminary findings have been useful in informing this Proposed Project's planning. The Parking Project is one element of Massport's overall trip reduction strategy, targeting reduction of drop-off/pick-up trips. It is expected that the studies will be complete in late summer 2019.
3-4	Marc D. Draisen, Executive Director, MAPC	Taxi Cabs, TNCs	MAPC recognizes that due to their rapid growth and ready availability, app-based ride hailing options could present a challenge to airport ground operations. MAPC requests that Massport analyze, as part of the scope for the EIR, the extent to which TNC trips are impacting access to and from Logan Airport.	Massport continues to carefully monitor and evaluate the evolving TNC industry and its impacts on access at Logan Airport. Earlier this year, Massport adopted a series of strategies to manage TNC growth and associated roadway congestion. These strategies are summarized in Chapter 3, *Existing/ Affected Environment*, Section 3.3.1.2.
3-5	Marc D. Draisen, Executive Director, MAPC	Taxi Cabs, TNCs	This study should also explore implementing a policy that requires taxis and TNCs not to deadhead when either arriving at or departing from Logan Airport. Requiring taxis and TNCs to carry air passengers both when entering and exiting Logan Airport could increase the efficient management of these trips, and negate all or part of the need for additional on-site parking.	As a parallel effort, Massport is evaluating mechanisms to reduce deadheading. In May 2019, the Massport Board of Directors voted to approve a new ground transportation plan to help mitigate traffic congestion in and around Logan Airport. The plan includes adding a $3.25 drop-off fee - effective October 1, 2019 - for TNC operations (the existing $3.25 pick-up fee will remain as is); incentivizing TNC shared-ride customers with a discounted fee of $1.50; allowing TNC drop-offs at the terminal curb Arrivals Level from 4:00 to 10:00 AM; and requiring all TNC pick-ups at a new, dedicated central location on the ground floor of the Central Garage. These aspects of the plan are expected to reduce deadhead trips by as much as a third.
3-6	Marc D. Draisen, Executive Director, MAPC	Taxi Cabs, TNCs	In fact, we think it highly likely that TNCs are already having a sizeable impact on travel patterns, and they influence is almost certain to grow	Comment noted.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
3-6 (cont.)			between now and the time the requested parking spaces are built.	
3-7	Marc D. Draisen, Executive Director, MAPC	Taxi Cabs, TNCs	Our perspective is that the link between the lack of parking and pick-up/drop-off activity, while plausible, is not proven, and providing that proof should be a considerable objective of the EIR.	This issue was thoroughly reviewed by MassDEP and the U.S. Environmental Protection Agency (EPA) as part of their review and approval of the amendment to the Logan Airport Parking Freeze. The Logan Airport Parking Project is consistent with the amendment to the Logan Airport Parking Freeze and the State Implementation Plan.
3-8	Marc D. Draisen, Executive Director, MAPC	Tolling and Fees	MAPC requests that Massport prepare a study that evaluates the incorporation of fees for pick-up/drop-off activity.	Comment noted. As part of the MassDEP and EPA reviews of the amendment to the Logan Airport Parking Freeze, Massport was not required to evaluate fees for pick-up/drop-off activity and that issue was not a part of the EIR scope.
4-1	John Sullivan, P.E., Chief Engineer, BWSC	Water	Identify specific best management measures for controlling erosion and preventing the discharge of sediment, contaminated storm water or construction debris to the Commission's drainage system when construction is underway. • Include a site map which shows, at a minimum, existing drainage patterns and areas used for storage or treatment of contaminated soils, groundwater or stormwater, and the location of major control structures or treatment structures to be utilized during the construction. • Specifically identify how the project will comply with the Department of Environmental Protection's Performance Standards for Stormwater Management both during construction and after construction is complete.	Specific best management practices for controlling erosion and sedimentation will be determined as the design progresses and construction specifications are developed. Existing drainage patterns are shown on Figure 3-11 in Chapter 3, *Existing/Affected Environment*. Areas used for storage or treatment of contaminated soils, groundwater or stormwater, and the location of major control structures or treatment structures to be utilized during construction have not yet been determined but will be developed as part of the construction specifications. These locations and practices will be coordinated with the requirements of the National Pollutant Discharge Elimination System (NPDES) permit. Due to the distance between the Project Areas and areas subject to the jurisdiction of the Wetlands Protection Act, the project is not subject to MassDEP's Stormwater Standards. Stormwater Management during construction will be in accordance with the EPA's NPDES General Permit for Construction Activities.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
4-2	John Sullivan, P.E., Chief Engineer, BWSC	Water	As stated in the ENF, the project will be required to obtain an NPDES General Permit for Construction from the Environmental Protection Agency and the Massachusetts Department of Environmental Protection because the project will disturb more than one acre of land. It is required that a copy of the permit and any pollution prevention plan prepared pursuant to the permit be provided to the Commission's Engineering Services Department, prior to the commencement of construction. The pollution prevention plan submitted pursuant to a NPDES Permit may be submitted in place of the pollution prevention plan required by the Commission provided the Plan addresses the same components identified in item I above.	As noted in Chapter 4, *Assessment of Impacts/Environmental Consequences*, Section 4.5.6.4, since the new garage in front of Terminal E involves construction disturbance of greater than one acre of land, a project-specific Stormwater Pollution Prevention Plan will be prepared in accordance with the EPA's NPDES Construction General Permit. The plan will ensure that construction activities do not result in impacts to water quality within Boston Harbor. It will identify specific best management measures for controlling erosion and preventing the discharge of sediment, contaminated stormwater, or construction debris to the existing drainage system during construction. The Boston Water and Sewer Commission requires a copy of this Stormwater Pollution Prevention Plan be submitted for its review and approval prior to commencement of construction.
4-3	John Sullivan, P.E., Chief Engineer, BWSC	Water	As stated in the ENF, Massport develops dewatering and discharge plans for all construction plans at Logan Airport. If required, groundwater treatment and discharge construction practices will be defined and submitted to MassDEP for approval. The discharge of dewatering drainage to a sanitary sewer is prohibited by the Commission. Massport is advised that the discharge of any dewatering drainage to the storm drainage system requires a Drainage Discharge Permit from the Commission. If the dewatering drainage is contaminated with petroleum products, the proponent will be required to obtain a Remediation General Permit from the Environmental Protection Agency (EPA) for the discharge.	As noted in Chapter 4, *Assessment of Impacts/Environmental Consequences*, Section 4.5.6.4, Massport develops a dewatering and discharge plan for all construction projects at Logan Airport. If required, groundwater treatment and discharge construction practices would be defined and submitted to MassDEP for approval and implemented during construction. Massport would not discharge storm or groundwater to the sanitary sewer system. If discharge of any dewatering drainage to the storm drainage system is required, Massport will obtain a Drainage Discharge Permit from the Boston Water and Sewer Commission. If the dewatering drainage is contaminated with petroleum products, Massport will obtain a Remediation General Permit from the EPA for the discharge.
4-4	John Sullivan, P.E., Chief Engineer, BWSC	Water	The Commission requests that Massport install a permanent casting stating "Don't Dump: Drains to Boston	As noted in Chapter 4, *Assessment of Impacts/Environmental Consequences*, Section 4.5.6.2, as requested by the

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
4-4 (cont.)			Harbor" next to any catch basin created or modified as part of this project. Massport should contact the Commission's Operations Division for information regarding the purchase of the castings.	Boston Water and Sewer Commission, Massport will install permanent castings stating "Don't Dump: Drains to Boston Harbor" next to any catch basin created or modified as part of the Proposed Project. Massport will contact the Boston Water and Sewer Commission's Operations Division for information regarding the purchase of the castings.
4-5	John Sullivan, P.E., Chief Engineer, BWSC	Water	The enclosed floors of a parking garage must drain through oil separators into the sewer system in accordance with the Commission's Sewer Use Regulations. The Commission's Requirements for Site Plans, available by contacting the Engineering Services Department, include requirements for separators.	As noted in Chapter 4, *Assessment of Impacts/Environmental Consequences*, Section 4.5.6.2, floor drains for enclosed floors at the new garage in front of Terminal E and the Economy Garage expansion will drain through oil separators into the sewer system in accordance with the Boston Water and Sewer Commission's Sewer Use Regulations and Requirements for Site Plans.
5-1	Bill Schmidt, Vice Chair, Winthrop Board of Health	HOVs	As I stated in my January 20, 2017 letter to you on the Boston-Logan International Airport 2015 EDR, I have concerns about the Logan Airport Parking Proposal to build up to 5,000 new on-airport commercial parking spaces and its effects on the environment and the Winthrop community. This may affect the efforts to increase the use of High Occupancy Vehicles (HOVs), transit, and shared-ride options for travel to and from the airport and to minimize vehicle trips.	Massport continues to support and expand our HOV programs including Logan Express, and our partnerships with MBTA and private transit carriers. A key project goal is to reduce the number of single occupancy trips to and from Logan Airport. A summary of the recent and pending HOV initiatives is provided in Chapter 3, *Existing/Affected Environment*, Section 3.3.1.2
5-2	Bill Schmidt, Vice Chair, Winthrop Board of Health	Air Quality, Climate Change, and VMT Environmental Concerns	Rather than amending the existing Logan Airport Parking Freeze Regulation (310 CMR 7.30) to allow for 5,000 more on-airport parking spaces, a lower amount combined with other measures should be implemented to reduce local and regional vehicle miles traveled (VMT) and vehicle air emissions associated with greater access to Boston-Logan International Airport.	Both the MassDEP and the EPA have agreed that additional parking at Logan Airport can reduce overall vehicle trips. A key project goal is to reduce the number of single occupancy trips to and from Logan Airport and their associated emissions. Massport continues to explore and implement new measures to increase use of HOV modes which both reduce congestion and associated vehicle emissions.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
5-3	Bill Schmidt, Vice Chair, Winthrop Board of Health	Parking Spaces Layout and Designations	Efforts should be made to convert significant additional on-airport employee spaces to in-service commercial spaces	Massport has periodically shifted employee parking to commercial parking (and that shift cannot be reversed). Currently, Massport has 2,448 designated employee parking spaces as compared to 5,225 spaces in 2000 and 7,100 in 1993 when Logan Airport handled just over 24 million annual passengers.
5-4	Bill Schmidt, Vice Chair, Winthrop Board of Health	Parking Spaces Layout and Designations	Consideration should be given to methods to reduce the amount of commercial parking for periods greater than 4 days by large increased rates for these days, which should increase turnover.	Massport's parking pricing is designed to encourage longer stays and fewer trips.
5-5	Bill Schmidt, Vice Chair, Winthrop Board of Health	Parking Spaces Layout and Designations	Instead of building new parking garage facilities at both the Economy Garage (Site 1) and the Terminal E Surface Lot (Site 2), building at the Terminal E Surface Lot alone could accommodate 3,000 spaces and its proximity to the Airport terminals provides an opportunity for parkers to walk to their respective terminals, reducing the need for operational resources (such as shuttle bus service) and reducing resultant on-Airport VMT.	Chapter 2, *Alternatives Analysis*, discusses the proposed spaces and phasing for the two parking locations.
5-6	Bill Schmidt, Vice Chair, Winthrop Board of Health	Parking Spaces Layout and Designations	In addition, Massport should make it a priority to convert the remaining 702 Park and Fly spaces in the East Boston Freeze Cap to commercial spaces at Logan Airport.	Massport will consider conversion of the remaining spaces as those properties become available.
5-7	Bill Schmidt, Vice Chair, Winthrop Board of Health	Transportation Planning and Studies	Massport has proposed several broad mitigation commitments to MassDEP associated with their proposed Parking Freeze amendment. Massport has proposed three long-term studies: Ways to improve HOV access to the Airport; Strategies for reducing drop-off/pick-up modes; and Parking pricing strategies. These should be completed at the earliest possible date.	It is expected that these studies will be complete in late summer 2019.
6-1	Richard Doherty, President, Association of Independent	Project Need and Support	Logan Airport is an essential economic engine for the region, and it needs the capacity in its facilities to meet its customers' needs as efficiently as	Comment noted.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
6-1 (cont.)	Colleges and Universities in Massachusetts		possible with minimal impact on the environment and the surrounding neighborhoods.	
6-2	Richard Doherty, President, Association of Independent Colleges and Universities in Massachusetts	Project Need and Support	To address current constraints and accommodate future passenger growth, Massport is proposing a measured increase in its on-airport parking as a component of their broader goals of customer service and community and environmental stewardship. We fully support this effort and encourage you to do the same.	Comment noted.
7-1	Richard C. Lord, President and Chief Executive Officer, Associated Industries of Massachusetts	Project Need and Support	As an economic engine for the region, Logan needs to enhance its facilities to meet customers' needs as efficiently as possible with minimal impact on the environment and the surrounding neighborhoods.	Comment noted.
7-2	Richard C. Lord, President and Chief Executive Officer, Associated Industries of Massachusetts	Project Need and Support	To address current constraints and accommodate future passenger growth, Massport is proposing a measured increase in its on-airport parking as a component of their broader goals of customer service and community and environmental stewardship. We fully support this effort and encourage you to do the same.	Comment noted.
8-1	William Guenther Chairman, CEO and Founder, Mass Insight Global Partnerships	Project Need and Support	To address this growing parking need and to prepare for the future, Massport is proposing to increase its on-airport parking as a component of the broader goals of customer service and community and environmental stewardship. We appreciate your consideration and fully support this important project for Boston and the New England Region.	Comment noted.
9-1	Christopher R. Anderson, President, Massachusetts High Technology Council	Project Need and Support	Logan Airport is an essential economic engine for the region, and it needs the capacity in its facilities to meet its customers' needs as efficiently as possible with minimal impact on the environment and surrounding neighborhoods.	Comment noted.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
9-2	Christopher R. Anderson, President, Massachusetts High Technology Council	Project Need and Support	To address current constraints and accommodate future passenger growth, Massport is proposing a measured increase in its on-airport parking as a component of their broader goals of customer service and community and environmental stewardship. We fully support this effort and encourage you to do the same.	Comment noted.
10-1	Louis A. Mandarini, Jr., Dominic C. Ottaviano, Local 22 Construction and General Laborers' Union	Project Need and Support	On behalf of Laborers' Local 22 I am writing to express support for Massport's request to amend the Logan Airport Parking Freeze to add 5,000 parking spaces at the airport.	Comment noted.
10-2	Louis A. Mandarini, Jr., Dominic C. Ottaviano, Local 22 Construction and General Laborers' Union	Project Need and Support	With Logan setting new passenger records every year, there should be some ability to expand parking to respond to the growth the airport has seen. This will not only create jobs, it will benefit the flying public and the environment.	Comment noted.
11-1	Dan O'Connell, President and CEO, Massachusetts Competitive Partnership	Project Need and Support	To address infrastructure constraints and to accommodate future passenger growth, Massport is proposing a measured increase in its on-airport parking as a part of their broader goals of providing high quality customer service and doing so in an environmentally friendly manner. I support Massport's efforts to increase their parking capacity which will better serve the traveler and the environment.	Comment noted.
12-1	Peter Forman, President and CEO, South Shore Chamber of Commerce	Project Need and Support	Logan Airport is an essential economic engine for the entire region and it needs the capacity in its facilities to meet its customers' needs as efficiently as possible with minimal impact on the environment and the surrounding neighborhoods.	Comment noted.
12-2	Peter Forman, President and CEO	Project Need and Support	In order to attract businesses and residents from outside the region to fuel this growth it is critical we have reliable parking and facilities at Logan.	Comment noted.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
12-3	Peter Forman, President and CEO	Project Need and Support	To address current constraints and accommodate future passenger growth, Massport is proposing a measured increase in its on-airport parking as a component of their broader goals of customer service and community and environmental stewardship. We fully support this effort and encourage you to do the same.	Comment noted.
13-1	Matthew Barison	Local Impacts and Mitigation	As you know, East Boston is disproportionately impacted by Logan Airport operations, and with the expansion of Terminal E, we can expect more flights, especially during the night time, when they are the most disruptive. I understand that the Terminal E expansion is a different project from this one, but the two are most certainly related.	Comment noted. The Proposed Project would not affect the number of flights or aircraft ground operations at Logan Airport.
13-2	Matthew Barison	Transportation Infrastructure and Operations Improvements	I would implore that as a condition of lifting the Parking Freeze, the Commonwealth be instructed to move forward with the construction (not further study) of the Red/Blue connector at Charles/MGH, as was originally mandated as mitigation for the Big Dig.	Comment Noted. This was not a condition of the amendment to the Logan Airport Parking Freeze by MassDEP or EPA.
13-3	Matthew Barison	Transportation Infrastructure and Operations Improvements	Extension of Blue line service from Wonderland to Lynn would also reduce the number of vehicles traveling to the airport from the North Shore and warrants further exploration.	Comment noted.
13-4	Matthew Barison	Transportation Infrastructure and Operations Improvements	The Silver Line would be orders of magnitude more useful if the following improvements were made: (1) signal priority when Silver Line vehicles exit the tunnel in South Boston @ D St., (2) a dedicated MBTA employee at Silver Line Way to assist with the transition from electric to diesel power, rather than the current system which has the bus operator leave the vehicle, (3) access to the TWT Eastbound via the ramp by State Police Station E4 rather	Comments noted. Massport continues to collaborate closely with MBTA on measures to improve the efficiency and capacity of the SL1 Route including adding 8 additional buses to the route. The new SL3 route between Chelsea and South Boston also makes a stop at the Blue Line Airport Station.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
13-4 (cont.)			than the cumbersome loop around the Massport Haul Road (which can increase travel times by up to 15 minutes in heavy traffic), (4) dedicated lanes within the airport, and (5) a new dedicated harbor tunnel between South Boston and Logan Airport solely for the use of the Silver Line and other HOV vehicles.	
13-5	Matthew Barison	Transportation Infrastructure and Operations Improvements	Additional Logan Express routes (coupled with further investments in HOV lanes on major highways) would also reduce the demand for parking. Why not try these first before lifting the parking freeze?	As discussed in this document, additional parking at Logan Airport is one part of Massport's overall ground access strategy. Continued improvements to and expansion of the Logan Express services remain a high Massport priority.
13-6	Matthew Barison	Local Impacts and Mitigation	If, however, your office does decide to lift the parking freeze and allow the construction of 5,000 new spaces at the Central Parking lot and Economy Lot, I would request that Massport be required to provide further mitigation to the East Boston community.	In advancing discussions regarding the Proposed Project and the Terminal E Modernization Project, Massport held many community discussions including numerous discussions about additional community benefits. As part of these discussions, Massport has agreed to advance design and construction of Piers Park II along the East Boston waterfront. Massport's Community Relations and Government Affairs Department works closely with the Airport's neighbors and impacted communities to support local activities and facilities. Massport's robust, non-Project related benefits provided to the community are documented in the Logan Airport EDRs and ESPRs.
13-7	Matthew Barison	Tolling and Fees	Furthermore, another easy way to raise revenue for such mitigation projects would be the implementation of a toll for private vehicles entering the airport. As the Commonwealth has now transitioned to AET, it would be easy to erect toll gantries at the airport entrances which assessed a small fee, such as $1, to private, noncommercial vehicles entering airport property. These revenues could be earmarked for East Boston mitigation projects.	Massport has developed a robust program to address management of TNC operations and enhancement of HOV goals. In May 2019, the Massport Board of Directors voted to approve a new ground transportation plan to help mitigate traffic congestion in and around Logan Airport. The plan includes adding a $3.25 drop-off fee - effective October 1, 2019 - for TNC operations (the existing $3.25 pick-up fee will remain as is); incentivizing TNC shared-ride

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
13-7 (cont.)				customers with a discounted fee of $1.50; allowing TNC drop-offs at the terminal curb Arrivals Level from 4:00 to 10:00 AM; and requiring all TNC pick-ups at a new, dedicated central location on the ground floor of the Central Garage. These aspects of the plan are expected to reduce deadhead trips by as much as a third.
13-8	Matthew Barison	Local Impacts and Mitigation	There are many worthy mitigation projects, and I will suggest just some. A committee of East Boston activists should be convened to determine funding priorities after increased revenues from additional parking fees and/or tolls are ascertained.	Massport convened the Logan Impact Advisory Group (LIAG), consisting of approximately 20 community representatives, that has already met on several occasions to discuss community mitigation priorities.
13-9	Matthew Barison	Local Impacts and Mitigation	Some suggestions for mitigation include: funding of Piers Park Phase II, extension of the East Boston Greenway, modernization of outdated East Boston public schools, supplemental bus service in East Boston to increase the frequency of current MBTA bus service, Massport subsidization of inner harbor ferries, a new round of window upgrades and soundproofing for residents within certain DNL contours, air filtration to reduce vehicle based emissions within the airport roadway system, a larger cell phone lot, increased electrification of ground access vehicles, supplemental water quality sampling at Constitution Beach, the purchase of vacant lots for the preservation of green space, improvement to landscaping within East Boston, planting of trees, etc.	In advancing discussions regarding the Proposed Project and the Terminal E Modernization Project, Massport held many community discussions including numerous discussions about additional community benefits. As part of these discussions, Massport has agreed to advance design and construction of Piers Park II along the East Boston waterfront. Massport's Community Relations and Government Affairs Department works closely with the Airport's neighbors and impacted communities to support local activities and facilities. Massport's robust, non-Project related benefits provided to the community are documented in the Logan Airport EDRs and ESPRs.
14-1	Patricia J. D'Amore	Taxi Cabs, TNCs	Massport has stated that one of their reasons for wanting more parking is to reduce the number of drop-off and pick-up trips (kiss and drop) by friends and relatives. If this is true, why has Massport recently allowed Uber and Lyft access to the airport AND given them their own parking lot! Since	Massport has developed a robust program to address management of TNC operations and enhancement of HOV goals. Recently, the Massport Board of Directors voted to approve a new ground transportation plan to help mitigate traffic congestion in and around Logan Airport. The plan includes adding

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
14-1 (cont.)			these are paid parking lots, is this an attempt by Massport to back-door their way around the freeze?	a $3.25 drop-off fee - effective October 1, 2019 - for TNC operations (the existing $3.25 pick-up fee will remain as is); incentivizing TNC shared-ride customers with a discounted fee of $1.50; allowing TNC drop-offs at the terminal curb Arrivals Level from 4:00 to 10:00 AM; and requiring all TNC pick-ups at a new, dedicated central location on the ground floor of the Central Garage. These aspects of the plan are expected to reduce deadhead trips by as much as a third.
14-2	Patricia J. D'Amore	Local Impacts and Mitigation	The increased air pollution and noise pollution in our neighborhoods due to increased airplane and vehicular traffic is unacceptable.	Implementation of the Proposed Project would allow Massport to reduce the adverse environmental impacts that would continue to occur if no action were taken, including higher regional VMT and associated air emissions from an increasing drop-off/pick-up mode share resulting from a parking supply that fails to meet air passenger demand during significant parking events. The Proposed Project would not affect aircraft ground operations or aircraft flights.
14-3	Patricia J. D'Amore	Transportation Planning and Studies	The lack of a comprehensive plan for all future expansion planned by Massport needs to be addressed. Cumulative effects cannot be measured adequately when all the projects are presented piecemeal.	Massport provides annual updates on Logan Airport activity and annual impacts including near and long-term planning initiatives. The EDR and ESPR filings are specifically designed to provide that cumulative impact context.
14-4	Patricia J. D'Amore	Transportation Planning and Studies	A plan to regionalize domestic flights to lessen the impact of increased international flights should be implemented.	The Proposed Project would not affect the number of flights or aircraft ground operations. As evidenced by its substantial investments in both the Worcester Regional Airport and Hanscom Field, Massport does continue to support regionalization. Activity at the regional airports is tracked annually through the EDR and ESPR filings.
15-1	Frederick P Salvucci	Transportation Planning and Studies	The proposal by Massport should be deferred until a comprehensive set of alternatives should be developed, with	The proposal to add new spaces was carefully reviewed by MassDEP and the EPA as part of the public process to

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
15-1 (cont.)			public participation, for alternatives to adding parking spaces to an airport which is already generating far too much traffic in the limited capacity of the Cross harbor tunnels.	amend the Logan Parking Freeze. Both agencies agreed that additional on-Airport parking could help reduce trips to and from Logan Airport and reduce vehicle emissions.
15-2	Frederick P Salvucci	Transportation Infrastructure and Operations Improvements	Massport should be required to build the underpass for the silver line at D street in South Boston that is required to improve travel time reliability and capacity on the Silver Line connection to Logan airport. This grade separation will enhance the value of the Massport real estate that it rests upon, and would improve the operating conditions of D street necessary to the functioning of the Seaport /Innovation District, where Massport owns significant real estate and seaport assets, and is a reasonable responsibility of Massport.	Comment noted.
15-3	Frederick P Salvucci	Transportation Infrastructure and Operations Improvements	Massport should institute any safety inspection required to allow the silver line to use the "state police " ramp, which is the most direct route for the Silver Line to Logan, the route that was presented to the public and approved in the environmental process which add the Silver Line connection to Logan to the South Boston Transitway during the 1990s.	Massport continues to work with MBTA, Massachusetts Department of Transportation (MassDOT), and the Massachusetts State Police in evaluating this recommendation. Implementation of a pilot program to test use of the ramp is planned for Fall 2019.
15-4	Frederick P Salvucci	Transportation Infrastructure and Operations Improvements	Massport should reinstitute the direct shuttle from Logan airport Station on the Blue Line to the Logan terminals, with direct services to terminals A and B, and C and E, as existed before Massport modified the routing to introduce the Rent a car facility between the Blue line station and the air terminals, thereby degrading the service which Massport had improved in the 1980s.	The consolidation of bus routes results in reduced VMT and associated air quality emissions. This is a primary goal of Massport. Massport will continue to evaluate the free shuttle bus routes and schedules.
15-5	Frederick P Salvucci	Transportation Infrastructure and Operations Improvements	Massport should institute free or very low cost bus service from Logan express sites, at double the current frequencies, and market the opportunity for Logan employees and	Massport continues to expand the hours of operation and frequencies of service at its busiest Logan Express site (Braintree & Framingham). Additional parking is also being planned for both

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
15-5 (cont.)			passengers to be dropped off and picked up by Friends or taxicabs or Uber and lift or local transit to the Logan Express site, with Massport providing the frequent and convenient and very low cost express bus connection to Logan.	locations. Massport also offers reduced bus and parking rates during peak demand periods. The Braintree Logan Express is now operating on 20-minute headways weekdays to provide additional HOV capacity. Massport has developed a robust program to address management of TNC operations and enhancement of HOV goals. In May 2019, the Massport Board of Directors voted to approve a new ground transportation plan to help mitigate traffic congestion in and around Logan Airport by expanding and incentivizing Logan Express service and changing how TNCs operate at the Airport. Logan Express initiatives include: 1) revitalizing Back Bay Logan Express service by moving it just outside MBTA's Back Bay Station, 2) starting a new urban service from North Station, 3) improving services or amenities at existing suburban sites, 4) building parking capacity at existing sites including 3,000 spaces at the Framingham and Braintree locations, and 5) identifying new suburban locations. Further, as of May 1, passengers who take the Back Bay Logan Express service now get ahead of the security line when they arrive at Logan, and the drop-off fee for this service was reduced from $7.50 to $3.00 to the Airport and free from the Airport. With respect to TNC operations, the plan includes adding a $3.25 drop-off fee – effective October 1, 2019 – for TNC operations (the existing $3.25 pick-up fee will remain as is); incentivizing TNC shared-ride customers with a discounted fee of $1.50; allowing TNC drop-offs at the terminal curb Arrivals Level from 4:00 to 10:00 AM; and requiring all TNC pick-ups at a new, dedicated central location on the ground floor of the Central Garage. These aspects of the plan are expected to

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
15-5 (cont.)				reduce deadhead trips by as much as a third.
15-6	Frederick P Salvucci	Transportation Infrastructure and Operations Improvements	Massport should also be required to add at least two new Logan Express suburban facilities with at least 2000 parking spaces at suburban locations to improve accessibility to Logan without auto use.	Massport continues to expand the hours of operation and frequencies of service at its busiest Logan Express sites (Braintree & Framingham). Additional parking is also being planned for both locations. Massport also offers reduced bus and parking rates during peak demand periods. The Braintree Logan Express is now operating on 20-minute headways weekdays to provide additional HOV capacity. Massport has developed a robust program to address TNC and HOV goals. Massport plans to double Logan Express ridership to 4 million passengers by improving Back Bay Logan Express service, starting a new urban Logan Express from North Station, enhancing services and amenities at existing suburban Logan Express sites, planning for and increasing parking capacity at existing sites, and identifying new suburban Logan Express locations. Massport is currently studying plans for adding the remaining parking spaces approved, but not built, for the Framingham Logan Express facility.
15-7	Frederick P Salvucci	Tolling and Fees	Massport should introduce an exit fee to access Logan airport, to be collected electronically from every vehicle which enters Logan, whether they park or not. This fee should be set high enough to reduce auto travel into Logan to below the capacity of the existing garages, and use the revenue to construct new Logan Express facilities, and fund increased frequency low cost express bus services from Logan Express to Logan. In addition, the fees should contribute financial support to MassDOT to construct the long delayed Blue to Red connector, in	Massport has developed a robust program to address TNC and HOV goals. Recently, the Massport Board of Directors voted to approve a new ground transportation plan to help mitigate traffic congestion in and around Logan Airport by expanding and incentivizing Logan Express service and changing how TNCs operate at the Airport. Logan Express initiatives include: 1) revitalizing Back Bay Logan Express service by moving it just outside MBTA's Back Bay Station, 2) starting a new urban service from North Station, 3) improving services/amenities at existing suburban sites, 4) building parking capacity at

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
15-7 (cont.)			order to improve Logan accessibility by transit. Finally, this fee should generate a revenue stream to contribute to the proper maintenance of the I -90 and Sumner and Callahan tunnels, which are critical to Logan access.	existing sites including 3,000 spaces at the Framingham and Braintree locations, and 5) identifying new suburban locations. Further, as of May 1, passengers who take the Back Bay Logan Express service now get ahead of the security line when they arrive at Logan, and the drop-off fee for this service was reduced from $7.50 to $3.00 to the Airport and free from the Airport. With respect to TNC operations, the plan includes adding a $3.25 drop-off fee - effective October 1, 2019 - for TNC operations (the existing $3.25 pick-up fee will remain as is); incentivizing shared-ride customers with a discounted fee of $1.50; allowing TNC drop-offs at the terminal curb Arrivals Level from 4:00 to 10:00 AM; and requiring all TNC pick-ups at a new, dedicated central location on the ground floor of the Central Garage. These aspects of the plan are expected to reduce deadhead trips by as much as a third.
15-8	Frederick P Salvucci	Taxi Cabs, TNCs	Massport should initiate a public awareness campaign to notify the public that there is likely to be low parking availability at Logan, and to encourage the use of taxicabs, and Uber and Lyft to access Logan without their autos.	This is a regular Massport program during peak travel periods.
15-9	Frederick P Salvucci	Taxi Cabs, TNCs	Massport lumps together taxicab and Uber and lift access with drop off and pick up, without recognizing that a well-regulated taxi and Uber/lift operation can match the one round trip by auto record of access of parking in the Logan garage. Massport should be required to work first with the taxicab industry to market the taxicab access model for trips not conveniently served by public transit, to give the cabs which have served Logan for decades first crack at this expandable market.	Massport regularly meets with representatives of the hackney and TNC industries to discuss operational efficiency measures and adjust those operations as both industries evolve. In May 2019, the Massport Board of Directors voted to approve a new ground transportation plan to help mitigate traffic congestion in and around Logan Airport. The plan includes adding a $3.25 drop-off fee - effective October 1, 2019 - for TNC operations (the existing $3.25 pick-up fee will remain as

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
15-9 (cont.)				is); incentivizing TNC shared-ride customers with a discounted fee of $1.50; allowing TNC drop-offs at the terminal curb Arrivals Level from 4:00 to 10:00 AM; and requiring all TNC pick-ups at a new, dedicated central location on the ground floor of the Central Garage. These aspects of the plan are expected to reduce deadhead trips by as much as a third.
15-10	Frederick P Salvucci	HOVs	Massport should initiate free transit passes to all airport employees, similar to the recent initiative at MIT, to encourage Massport and airport and concessionaire employees to use public transportation, and release employee parking spaces for general air passenger use.	A range of transit benefits are available to Massport and Airport-wide employees. These range from free boardings of the Silver Line at Logan (recently expanded to the Back Bay Logan Express route) and significantly reduced fares and parking at the four suburban Logan Express sites. Massport also provides free bus connections between the MBTA Blue Line and all terminals, including the Water Transportation Dock and the employee parking lot in Chelsea. Massport is evaluating ways to provide additional transit incentives to Airport employees.
15-11	Frederick P Salvucci	HOVs	Massport should also be required to contribute to MBTA all night service that will provide access to Airport employees during all hours.	Massport continues to expand Logan Express hours of service and also runs and subsidizes an early morning "Sunrise Shuttle" through parts of East Boston and Winthrop to provide coverage during the hours of the early morning when the MBTA system does not operate.
15-12	Frederick P Salvucci	Transportation Planning and Studies	Massport should also be required to initiate a new planning process to recognize that they have abandoned the commitments made in the 1980-1990 period to encourage regionalization of air travel demand and encourage its dispersion to Rhode Island, New Hampshire and Connecticut, and to High speed rail to New York via both Rhode Island and Worcester and Springfield, in order to not over stress the capacity of Logan.	As evidenced by our substantial investments in both the Worcester Regional Airport and Hanscom Field, Massport-continues to support regionalization. As compared to the relatively low rail utilization in the 1980s and 1990s, Amtrak now carries more passengers between Boston and New York than the airlines.

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
15-12 (cont.)			Massport should be required to develop anew this regionalization strategy in cooperation with neighboring states and AMTRAK.	
15-13	Frederick P Salvucci	Transportation Planning and Studies	Massport should be required to do a new conceptual plan for how Logan can possibly handle the air demand that it is generating with its airline subsidy policies, and review the physical constraints of the site.	Logan's current and projected growth is tied directly to regional economic growth. The forthcoming *2017 ESPR* includes operational and environmental forecasts for projected growth to 50 million annual air passengers. This includes discussions of airside and landside facility needs and on- and off-Airport ground access strategies to respond to this regional growth while continuing to manage environmental impacts.
15-14	Frederick P Salvucci	Transportation Planning and Studies	Very specifically, there should be no added garage construction at Logan until there is a new master plan that is comprehensive and identifies how the increased level of activity anticipated over the next twenty years can be accommodated on available airport land, and at what cost.	Massport's unique Logan Airport EDR/ESPR process continues to outline and update Massport's short- and long-term plans for Logan Airport. These reports include forecasts through 2030 and beyond.
15-15	Frederick P Salvucci	Air Quality, Climate Change, and VMT Environmental Concerns	Massport should be required to fund independent public health and environmental justice studies of the cumulative impact of current levels of air pollution generated by all Logan related activities, including truck and aviation related NOX and C02, to establish an honest baseline, against which any new traffic generation will need to be evaluated. It is a long recognized problem in environmental justice communities that it is the toxic mix of pollution from all sources that impacts the health of neighbors, in particular vulnerable neighbors who are elderly, young or frail. So it is essential to establish the current cumulative baseline. Identify means to reduce those levels, and then add the expected increment from any new initiative that may be considered.	Massport provided data and financial support to the Massachusetts Department of Public Health's (DPH) 2014 study of Logan Airport. Massport continues to provide data and information to third-party research studies on aviation emissions and public health. Massport continues to believe that research on the impacts of aviation should be addressed by the Federal Aviation Administration at the national level and we will continue to support that research. In the annual EDR/ESPR filings, Massport also tracks a range of emissions to assess long range air quality trends.
15-16	Frederick P Salvucci	Air Quality, Climate	Massport should be required to fund an independent assessment of the	Massport, through its annual EDR/ESPR filings, reports on Airport emissions including nitrogen oxides

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
15-16 (cont.)		Change, and VMT Environmental Concerns	contribution of Logan to climate change gas generation, specifically including aviation generation of Climate change gases like NOX.	(NOx). Since 2005, Massport has included estimates of Airport-wide greenhouse gas emissions. Individual project filings such as this DEIR also discuss greenhouse gas emissions. A key goal of the Proposed Project is to reduce VMT and associated emissions.
16-1	John Vitagliano	Project Need and Support	I strongly endorse the Massachusetts Port Authority (Massport) 's Environmental Notification Form (ENF) for the Logan Airport Parking Project. I have thoroughly reviewed the entire document and believe that it fully and accurately depicts the current traffic difficulties and environmental degradation associated with ground transportation access to Logan Airport and that it proposes an appropriate remediation program that is simultaneously environmentally responsible and functionally effective.	Comment noted.
17-1	Wig Zamore	Air Quality, Climate Change, and VMT Environmental Concerns	Logan Airport and its operations are the single largest source of air pollution and noise in New England. Surface transportation is an important component of Logan's local and regional impacts.	Implementation of the Proposed Project would allow Massport to avoid adverse environmental impacts if no action were taken, including higher regional VMT and associated emissions from an increasing drop-off/pick-up mode share resulting from a parking supply that fails to meet air passenger demand during significant parking events. Chapter 4, *Assessment of Impacts/Environmental Consequences* demonstrates that the Proposed Project would have air quality benefits when compared to the No-Build Alternative due to reduced regional VMT, and the additional parking levels on the Economy Garage would have noise barrier benefits to the community in conjunction with the Terminal E Modernization Project. The Proposed Project would not affect aircraft ground operations or aircraft flights.
17-2	Wig Zamore	Air Quality, Climate	Those impacts cannot be eliminated, but they must be managed through the	Massport works diligently to minimize the impacts associated with Airport

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
17-2 (cont.)		Change, and VMT Environmental Concerns	collaboration of Massport, its workers and users, neighbors, and other impacted citizens.	operations that are under its control. These measures are detailed annually in the EDR and ESPR filings.
17-3	Wig Zamore	Air Quality, Climate Change, and VMT Environmental Concerns	There is no reason that Massport, the Boston MPO and MassDEP cannot includes SLCP [short-lived climate pollutants], most importantly BC [black carbon], in climate assessments. We do not have to reinvent the science to do this. Just apply it!	Massport assesses particulate matter associated with Airport activities and reports on an annual basis in the EDR and ESPR filings.
17-4	Wig Zamore	Tolling and Fees	Now that MassDOT has transponder based highway tolling why not charge for curb-side Kiss-n-Drop?	Massport has developed a robust program to address TNC and HOV goals. Recently, the Massport Board of Directors voted to approve a new ground transportation plan to help mitigate traffic congestion in and around Logan Airport by expanding and incentivizing Logan Express service and changing how TNCs operate at the Airport. Logan Express initiatives include: 1) revitalizing Back Bay Logan Express service by moving it just outside MBTA's Back Bay Station, 2) starting a new urban Logan Express from North Station, 3) improving services/amenities at existing suburban Logan Express sites including greater frequencies, 4) building parking capacity at existing sites including 3,000 spaces at the Framingham and Braintree locations, and 5) identifying new suburban Logan Express locations. Further, as of May 1, passengers who take the Back Bay Logan Express service now get ahead of the security line when they arrive at Logan, and the drop-off fee for this service was reduced from $7.50 to $3.00 to the Airport and free from the Airport. With respect to TNC operations, the plan includes adding a $3.25 drop-off fee - effective October 1, 2019 - for TNC operations (the existing $3.25 pick-up fee will remain as is); incentivizing

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
17-4 (cont.)				shared-ride customers with a discounted fee of $1.50; allowing TNC drop-offs at the terminal curb Arrivals Level from 4:00 to 10:00 AM; and requiring all TNC pick-ups at a new, dedicated central location on the ground floor of the Central Garage. These aspects of the plan are expected to reduce deadhead trips by as much as a third.
17-5	Wig Zamore	Transportation Infrastructure and Operations Improvements	With implementation of Phase 3 Urban Ring, Logan would not have to build another parking space and our economy, including the struggling Gateway Cities, would hum!	The Logan Airport Parking Garage Project is just one component of Massport's ground access strategy. Since the mid-1970s, Massport has been committed to increasing the use of HOV ground transportation modes for passengers traveling to and from Logan Airport, with a current goal of 40 percent HOV by 2027. Chapter 1, *Project Description/Purpose and Need* presents a list of measures implemented by Massport to increase HOV use. These measures relate to pricing (incentives and disincentives), service availability, service quality, marketing, and traveler information. Phase 3 of the MBTA's Urban Ring Project is not currently funded and is not listed in the Long-Range Transportation Plan for the Boston Region.
17-6	Wig Zamore	Transportation Infrastructure and Operations Improvements	Massport ought to operate Logan with a real target of 50% or greater clean transit and HOV, 50% or less private autos and low occupancy vehicles, and work with all of us to accomplish that as soon as possible.	Massport has developed a robust program to address TNC and HOV goals. Recently, the Massport Board of Directors voted to approve a new ground transportation plan to help mitigate traffic congestion in and around Logan Airport by expanding and incentivizing Logan Express service and changing how TNCs operate at the Airport. Logan Express initiatives include: 1) revitalizing Back Bay Logan Express service by moving it just outside the MBTA's Back Bay Station, 2) starting a new urban Logan Express

Table B-2 Responses to Public Comments on the Logan Airport Parking Project Environmental Notification Form (Continued)

Comment #	Author	Topic	Comment	Response
17-6 (cont.)				from North Station, 3) improving services/amenities at existing suburban Logan Express sites including greater frequencies, 4) building parking capacity at existing sites including 3,000 spaces at the Framingham and Braintree locations, and 5) identifying new suburban Logan Express locations. Further, as of May 1, passengers who take the Back Bay Logan Express service now get ahead of the security line when they arrive at Logan, and the drop-off fee for this service was reduced from $7.50 to $3.00 to the Airport and free from the Airport. With respect to TNC operations, the plan includes adding a $3.25 drop-off fee - effective October 1, 2019 - for TNC operations (the existing $3.25 pick-up fee will remain as is); incentivizing shared-ride customers with a discounted fee of $1.50; allowing TNC drop-offs at the terminal curb Arrivals Level from 4:00 to 10:00 AM; and requiring all TNC pick-ups at a new, dedicated central location on the ground floor of the Central Garage. These aspects of the plan are expected to reduce deadhead trips by as much as a third.

Appendix C

- Draft Section 61 Findings

This Page Intentionally Left Blank.

DRAFT PROJECT § 61 FINDINGS FOR THE PARKING PROJECT AT BOSTON-LOGAN INTERNATIONAL AIRPORT

PROPOSED RESOLUTION AND VOTE OF THE BOARD OF THE MASSACHUSETTS PORT AUTHORITY IN COMPLIANCE WITH M. G. L. c. 30, § 61

WHEREAS, over 90 percent of Boston-Logan International Airport (Logan Airport or the Airport) travelers are origin and destination passengers and therefore use some form of local ground transportation to reach their final destinations; and

WHEREAS, passenger demand at Logan Airport has grown substantially over the past four decades, and particularly in the past three years, and current forecasts project that Logan Airport will serve 50 million air passengers annually within a 10- to 15-year planning horizon; and

WHEREAS, this growth of passenger demand at Logan Airport has occurred without any comparable increases in Airport parking; and

WHEREAS, the shortage of available parking spaces has the unintended effect of causing severe congestion on Airport roadways and negatively impacting air quality; and

WHEREAS, the number of commercial and employee parking spaces allowed at Logan Airport is regulated by the Massachusetts Department of Environmental Protection (MassDEP) through the Logan Airport Parking Freeze (Parking Freeze), which is an element of the Massachusetts State Implementation Plan (SIP) under the federal Clean Air Act; and

WHEREAS, the Parking Freeze was originally adopted in 1975 by the United States Environmental Protection Agency (EPA) under the federal Clean Air Act and was intended to reduce automobile emissions and enable Massachusetts to achieve compliance with the National Ambient Air Quality Standards (NAAQS) for carbon monoxide (CO) at localized sites and for ozone on a regional basis; and

WHEREAS, the Massachusetts Port Authority (Massport or the Authority) worked with MassDEP on an amendment to the Parking Freeze to increase the parking freeze limit by 5,000 spaces in parallel with the development of the Environmental Notification Form (ENF) for the Logan Airport Parking Project under the Massachusetts Environmental Policy Act (MEPA); and

WHEAREAS, MassDEP approved the requested parking increase and issued the amended regulation on June 30, 2017; and

WHEREAS, the U.S. Environmental Protection Agency (EPA) approved the proposed rule to revise the SIP to incorporate the amended Logan Airport Parking Freeze on March 6, 2018, and the rule went into effect on April 5, 2018; and

WHEREAS, by adding a total of 5,000 new commercial parking spaces, in two phases, (approximately 2,000 spaces at a new garage in front of Terminal E and approximately 3,000 spaces at an expanded Economy Garage), implementation of the Project will better accommodate current and projected increased passenger demand that is expected to occur whether or not the Project is implemented; and

WHEREAS, implementation of the Project would cause a substantial decrease in vehicle miles traveled (VMT) and associated emissions by reducing congestion and drop-off/pick-up mode share, thereby providing a significant air quality benefit; and

WHEREAS, implementation of the Project would also improve passenger experience; and

WHEREAS, on March 31, 2017, Massport filed an ENF pursuant to MEPA, proposing the Logan Airport Parking Project, and on May 5, 2017, the Secretary of the Executive Office of Energy and Environmental Affairs (the Secretary) issued a Certificate and Scope for the Project and its environmental studies under MEPA; and

WHEREAS, on May 5, 2017, the Secretary issued a Certificate on the ENF stating that "The DEIR should include a separate chapter summarizing proposed mitigation measures. This chapter should also include draft Section 61 Findings for each area of impact associated with Massport's Preferred Alternative. The DEIR should contain clear commitments to implement these mitigation measures, estimate the individual costs of each proposed measure, identify the parties responsible for implementation (either funding design and construction or performing actual construction), and a schedule for implementation. To ensure that all greenhouse gas emissions reduction measures adopted by the Proponent in the Preferred Alternative are actually constructed or performed by the Proponent, I require Proponents to provide a self-certification to the MEPA Office indicating that all of the required mitigation measures, or their equivalent, have been completed. The commitment to provide this self-certification in the manner outlined above should be incorporated into the draft Section 61 Findings included in the DEIR."

NOW THEREFORE BE IT RESOLVED AND VOTED:

A. The Authority hereby finds that: (a) the selection and implementation of the Project's Preferred Alternative and assessment of environmental impacts associated with the Project are properly and adequately described and evaluated in the EIR/EA; (b) the description of such environmental impacts set forth in said documents is adopted as a specific finding herein; and (c) by implementing the environmentally beneficial measures and mitigation measures set forth in the EIR/EA, as modified by and as authorized and directed by this resolution, all practicable means and measures will be taken to minimize damage to the environment. In making this finding, the Authority has considered reasonably foreseeable climate change impacts and effects, including greenhouse gas emissions and potential sea level rise.

B. The Authority hereby further finds and determines that the improvements constituting the Preferred Alternative for the Project, as set forth in the EIR/EA, will enhance the operation of Logan Airport and better serve the traveling public.

C. The Authority hereby makes the findings set forth below in accordance with M. G. L. c.30, § 61, and hereby authorizes and directs the CEO/Executive Director to implement the measures described herein.

1. Current and Future Parking Operations

Logan Airport's parking operations differ from other urban parking facilities in two important respects. First, due to the nature of air passenger travel, parking spaces at airports turn over (i.e., change vehicles) much less frequently. This requires more parking capacity than in an urban/workplace setting supporting the same number of vehicles. Second, in an urban core such as the City of Boston, daily/regular travel coupled with parking constraints encourage commuters to travel by high-occupancy vehicle (HOV) modes that are less environmentally harmful than other modes. Unlike urban commuters, however, air travelers do not travel to airports daily, so drop-off/pick-up modes and personal vehicle parking may be more practical options. When parking at Logan Airport is constrained, this can have the unintended adverse environmental consequence of encouraging drop-off/pick-up modes, which comparatively increases VMT and air emissions.

To address operational challenges and environmental conditions caused by the existing constrained parking supply at Logan Airport, Massport developed a Long-Term Parking Management Plan, which was first published in the *2012/2013 Logan Airport Environmental Data Report* (EDR). The Long-Term Parking Management Plan sets out a multi-element strategy for efficiently managing parking supply, pricing, and operations. Massport's goals are to maximize transit, shared-ride, and other HOV ground access, while both reducing parking demand and minimizing drop-off/pick-up activity.

2. Project Benefits

As demonstrated by its purpose, the implementation of the Project itself is an environmentally beneficial measure. As described below, the Project and its associated program elements will accommodate current and projected air passenger parking demand to reduce drop-off/pick-up activity, reduce VMT, improve regional air quality, and improve the passenger experience by adding 5,000 new commercial parking spaces (in accordance with the Parking Freeze) entirely within the Airport footprint. Approximately 2,000 spaces will be located in a new garage in front of Terminal E and approximately 3,000 spaces will be added to the existing Economy Garage through an expansion of the existing facility. With the exception of the temporary construction impacts described below, no significant adverse environmental impacts resulting from the implementation of the Project have been identified.

Table 1 summarizes the Project's benefits and construction-period mitigation commitments, as applicable, and identifies associated responsibilities and costs, as available. The implementation schedule for construction period mitigation measures aligns with the implementation of the Project elements and their phases (see Section 4, *Timing and Responsibility for Implementation*). Non-construction mitigation measures will be implemented as part of the design or operation of the Proposed Project elements.

Table 1 Summary of Logan Airport Parking Project Beneficial and Mitigation Measures

Beneficial/Mitigation Measure	Responsibility	Cost
Project Planning and Design		
■ Provide added noise barrier benefits to nearby residences and recreation areas, through the expansion of the existing Economy Garage	Massport	Included in Program Costs
■ Provide drivers with roadway and parking information through internal and external wayfinding systems	Massport	Included in Program Costs
■ Provide a pay-by-foot system that encourages parkers to use automated kiosks to pay their parking fees prior to returning to their vehicles	Massport	Included in Program Costs
Sustainability and Resiliency		
■ Incorporate measures from the U.S. Green Building Council's Parksmart rating system into the Proposed Project's technology, structural design, and operation	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Reduce lighting power densities for garage lighting	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Install occupancy sensors and photocells on all applicable interior and exterior lighting	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Incorporate a solar photovoltaic system at the new garage in front of Terminal E to offset approximately 60 percent of electricity consumption associated with the garage interior lighting or about 15 percent of the total facility electrical consumption	Massport/ Construction Contractor and Sub-contractors	$1.52 million – Included in Program Costs
■ Relocate the existing solar photovoltaic system at the Economy Garage to the top of the facility's new highest level upon completion of Project construction (the installation of a newer, more efficient system will be evaluated for feasibility as that construction period gets closer)	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Perform building commissioning in accordance with ASHRAE Guideline 0-2005 and ASHRAE Guideline 1.1-2007	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Reserve priority parking spaces for alternative fuel vehicles (e.g., electric vehicles) amounting to at least 1 percent of total spaces and assign preferred parking spaces for other low-emitting and fuel-efficient vehicles amounting to at least another 1 percent of total spaces	Massport	Included in Program Costs
■ Install electric vehicle charging stations to accommodate 150 percent of demand; 15 charging stations are currently planned for the new garage in front of Terminal E and five are planned for the Economy Garage expansion	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Integrate landscaping into the façade of the new garage in front of Terminal E	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs

Table 1 Summary of Logan Airport Parking Project Beneficial and Mitigation Measures (Continued)

Beneficial/Mitigation Measure	Responsibility	Cost
Sustainability and Resiliency (Continued)		
■ Plant water-conserving ground landscapes that apply the principles of xeriscaping (e.g., use of native plants)	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Harvest stormwater at the new garage in front of Terminal E to offset a portion of cooling tower water consumption at the Central Heating Plant, and assess the feasibility of stormwater collection at the Economy Garage as its design proceeds	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Perform frequent sweeping (at least monthly) to reduce the need for constant pressure washing and associated water use	Massport	TBD
■ Utilize power/pressure washing systems with water recovery and recycling capability to the greatest extent practicable	Massport	TBD
■ Install programmable thermostats, where applicable (i.e., mechanical/electrical rooms)	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Specify water efficient fixtures and faucets in a staff restroom at the new garage in front of Terminal E	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Implement a recycling program to reduce the amount of waste sent to regional landfills/incinerators and to reduce greenhouse gas emissions associated with material disposal	Massport	TBD
■ Apply durable design and conduct proactive maintenance to extend facility lifespan and avoid greenhouse gas emissions caused by future large-scale construction and renovation activities	Massport/ Construction Contractor	Included in Program Costs
■ Comply with Massport's *Floodproofing Design Guide* and elevate critical equipment and systems above the designated design flood elevations	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Ensure redundant or back-up power sources to reduce disruption from extreme weather conditions that may cause power outage	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Consider the following additional sustainability measures as design proceeds: ❑ Apply no/low volatile organic compound (VOC) coatings, paints, and sealants ❑ Prioritize product and material purchases based on their environmental sustainability (e.g., products that are refurbished, repurposed, or recycled)	Massport/ Construction Contractor	TBD
Construction Period Mitigation		
■ Provide on-Airport storage areas for construction materials	Massport/ Construction Contractor	Included in Program Costs
■ Require Massport's Construction Manager to prepare: ❑ Draft Soil Management Plan ❑ Draft Stormwater Pollution Prevention Plan ❑ Draft Management Plan for Dewatering (if needed) ❑ Draft Health and Safety Plan ❑ Draft Construction Waste Management Plan	Massport/ Construction Contractor	Included in Program Costs
■ Control rodents through routine inspection, monitoring, and treatment	Massport/ Construction Contractor	Included in Program Costs
■ Prioritize use of construction equipment and materials that are repurposed, reused, or recycled (or contain recycled content), where feasible	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs

Table 1 Summary of Logan Airport Parking Project Beneficial and Mitigation Measures (Continued)

Beneficial/Mitigation Measure	Responsibility	Cost
Construction Period Mitigation (Continued)		
■ Implement the following surface transportation construction-period mitigation measures: ❑ All trucks will access the sites by Route 1A, Interstate 90, and the main Airport roadway only ❑ Trucks will be prohibited from using local streets ❑ Truck routes will be specified in contractors' construction specifications ❑ Concrete production and batching will occur in existing plants with access via Route 1A or Interstate 90 ❑ Encourage construction workers to use Massachusetts Bay Transportation Authority (MBTA) transit services, Logan Express, the water shuttle, and other high-occupancy modes ❑ Encourage construction companies to provide off-Airport parking for their employees and to provide shuttle services from these locations (shuttles will be required to use the Coughlin Bypass road to access the Airport)	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Implement the following air quality construction-period mitigation measures: ❑ Construction vehicle/equipment anti-idling ❑ Using low- or zero-emissions equipment, where practicable ❑ Retrofitting appropriate diesel construction equipment with diesel oxidation catalyst and/or particulate filters ❑ Reducing on-site vehicle speeds ❑ Deploying air quality and fugitive dust management best practices such as reducing exposed erodible surface areas through appropriate materials and equipment staging, covering exposed surface areas with pavement or vegetation in an expeditious manner, and stabilizing soil with cover or periodic watering	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Use and maintain construction equipment appropriately to avoid unnecessary noise and apply noise-reduction measures to reduce noise from pile driving by at least 5 A-weighted decibels (dBA) below their unmitigated levels[1]	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Put an Erosion and Sedimentation Control Program into place, in compliance with the Stormwater Pollution Prevention Plan, to protect water quality and to minimize construction phase impacts to Boston Harbor	Massport/ Construction Contractor	Included in Program Costs
■ Deploy spill prevention measures and sedimentation controls throughout the construction phases to prevent pollution from construction equipment and erosion	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs
■ Use the following erosion and sedimentation controls: ❑ Perimeter barriers such as straw wattles or compost-filled "silt sock" barriers will be placed around upland work areas to trap sediment transported by runoff before it reaches the drainage system or leaves the construction site ❑ Existing catch basins within the work sites will be protected with barriers (where appropriate) or silt sacks ❑ Open soil surfaces will be stabilized within 14 days after grading or construction activities have temporarily or permanently ceased	Massport/ Construction Contractor and Sub-contractors	Included in Program Costs

Table 1 Summary of Logan Airport Parking Project Beneficial and Mitigation Measures (Continued)

Beneficial/Mitigation Measure	Responsibility	Cost
Construction Period Mitigation (Continued)		
■ Implement the following surface transportation construction-period mitigation measures to address the simultaneous construction of projects at the Airport: ❑ Hire a Strategic Projects consultant (a process Massport is currently conducting separate from the Proposed Project) Coordinate the arrival of large construction equipment among projects and limit their arrival or removal during peak travel hours (both Airport and commuter peaks) ❑ Develop specific truck routing and/or staging plans for implementation by the various contractors	Massport/ Construction Contractor	Included in Program Costs
Ground Access Improvement, Trip Reduction, and Emissions Reduction		
■ Implement the following ground access improvement, trip reduction, and emission reduction initiatives: ❑ Advance the electrification of ground service equipment, pursuant to which all ground service equipment will be replaced no later than the end of 2027 (as available) ❑ Expand Logan Express capacity by 10 percent ❑ Increase the percentage of zero emission taxi, livery, and transportation network company (TNC) vehicles by providing: high-speed electric vehicle charging stations at all taxi, livery, and TNC pools; and taxi and TNC queue priority to electric vehicles (subject to negotiation with companies)	Massport	TBD

Note:
1 Sound levels from activities associated with the construction of the Proposed Project would be voluntarily consistent with the City of Boston's noise criteria; therefore, no construction noise mitigation is anticipated.

Project Planning and Sustainable Design

The Project is sited entirely on-Airport in areas that have been selected with community input and are already developed and currently used for commercial parking. The Project Areas are separated from nearby residential communities: the new garage in front of Terminal E is largely surrounded by other Airport facilities and structures and the Economy Garage expansion by local roads, the Blue Line right-of-way, and Interstate 90/Route 1A. Both Project sites are served by existing Massport shuttle bus routes.

Massport will incorporate design features that specifically intend to improve operational efficiencies at the garages and enhance the passenger experience. The new garage in front of Terminal E will provide passengers with convenient access to the terminal buildings and to the pedestrian bridge that connects Terminal E to the Central Garage complex (which includes the West and Central Garages), and will include a secondary entrance for public parkers to reduce on-Airport recirculation. It will also include a vehicular bridge connected to the Central Garage complex to enable more efficient operational movements by Massport's Ground Transportation Unit (i.e., moving vehicles between the parking facilities in cases of overflow). The Economy Garage expansion will rely on existing roadway infrastructure and signage, and will have added noise barrier benefits, in conjunction with the Terminal E Modernization Project, screening the community and neighborhood recreation areas from aircraft ground noise in the North Apron Area. Common to both facilities, Massport will develop internal and external wayfinding systems to include dynamic signage, a parking reservation system, and parking guidance via electronic level occupancy detection. Massport will also implement its pay-by-foot system to encourage parkers to pay their parking fees at automated kiosks prior to returning to their vehicles, which reduces queuing at the garage exits. These wayfinding and pay-by-foot systems would support a reduction in on-Airport and in-facility circling and idling, resulting in fewer VMT and associated air emissions.

Massport is committed to operating its facilities in an environmentally sound and responsible manner. Accordingly, it incorporates Massport-specified sustainability requirements as well as industry standards into all new development and redevelopment projects at the Airport such as Massport's *Sustainable Design Standards and Guidelines* and the building goals of the U.S. Green Building Council's (USGBC's) Leadership in Energy and Environmental Design (LEED®) rating system. Specific to the Proposed Project, which involves the construction of structured parking, Massport will integrate USGBC's Parksmart framework into the planning, design, and operation of the proposed garages. Parksmart is an environmental and sustainability focused rating system specific to parking structure management, programming, design, and technology.

The Proposed Project will be consistent with Massport's overall sustainability program, which includes diverse sustainability initiatives ranging from facilities maintenance to innovative partnerships and public incentives. The sustainable features that Massport will incorporate into the design of the garages are listed below. Further sustainable design opportunities such as the application of no/low VOC coatings, paints, and sealants and the prioritization of product and material purchases based on their environmental sustainability will be addressed as the Proposed Project progresses into design development. These additional opportunities will be incorporated into the construction of the Proposed Project, especially as they relate to the proper specification of sustainable materials and construction practices, as well as into the operation of the facilities.

- Reducing lighting power densities for garage lighting;
- Installing occupancy sensors and photocells on all interior and exterior lighting, where applicable;
- Incorporating a solar photovoltaic system at the new garage in front of Terminal E to offset approximately 60 percent of electricity consumption associated with the garage interior lighting or about 15 percent of the total facility electrical consumption;
    - Massport is committed to further reducing the installed lighting power density at the new garage in front of Terminal E, currently 0.09 watts per square foot, by investigating current luminaires with greater efficacy toward the goal of offsetting 100 percent of the garage's interior lighting with on-site solar photovoltaics;

- Relocating the existing solar photovoltaic system at the Economy Garage to the top of the facility's new highest level upon completion of Project construction (the installation of a newer, more efficient system will be evaluated for feasibility as that construction period gets closer);
- Performing building commissioning in accordance with ASHRAE Guideline 0-2005 and ASHRAE Guideline 1.1-2007;
- Reserving priority parking spaces for alternative fuel vehicles (e.g., electric vehicles) amounting to at least 1 percent of total spaces and assigning preferred parking spaces for other low-emitting and fuel-efficient vehicles amounting to at least another 1 percent of total spaces;
- Installing electric vehicle charging stations to accommodate 150 percent of demand (measured as not more than 66.667 percent of charging stations in use at any time); 15 charging stations are currently planned for the new garage in front of Terminal E and five are planned for the Economy Garage expansion;
- Integrating landscaping into the façade of the new garage in front of Terminal E;
- Planting water-conserving ground landscapes that apply the principles of xeriscaping (e.g., use of native plants);
- Harvesting stormwater at the new garage in front of Terminal E to offset a portion of cooling tower water consumption at the Central Heating Plant and for other potential reuse applications, as feasible, and assessing the feasibility of stormwater collection at the Economy Garage expansion as design proceeds;
- Performing frequent sweeping (at least monthly) to reduce the need for constant pressure washing and associated water use;
- Utilizing power/pressure washing systems with water recovery and recycling capability to the greatest extent practicable;
- Installing programmable thermostats, where applicable (i.e., mechanical/electrical rooms);
- Specifying water efficient fixtures and faucets in a staff restroom at the new garage in front of Terminal E;
- Implementing an active recycling program to reduce the amount of waste sent to regional landfills/incinerators and to reduce greenhouse gas emissions associated with material disposal;
- Applying durable design (e.g., by minimizing steel corrosion by keeping steel away from the immediate concrete surface and selecting the appropriate concrete mix to reduce permeability, protect against chloride ion erosion, and reduce micro cracking) and conducting proactive maintenance to extend facility lifespan and avoid greenhouse gas emissions caused by future large-scale construction and renovation activities;
- Complying with Massport's *Floodproofing Design Guide* and elevating critical equipment and systems above the designated design flood elevations; and
- Ensuring redundant or back-up power sources to reduce disruption from extreme weather conditions that may cause power outage.

Surface Transportation Benefits

The Project will make surface transportation operations more efficient at Logan Airport. Airport VMTs will be lowered due to reduced circulation and drop-off/pick-up mode activity. This will reduce congestion on Airport roadways and at curbsides.

The Project will enhance passenger experience by reducing the need to divert parkers to off-Airport satellite parking locations. Parking in satellite locations increases the time it takes for air passengers to drop off their cars and access the terminal area, and also increases on-Airport VMT. Providing sufficient parking will also reduce the need for Massport to valet overflow parking during peak parking periods.

Air Quality Benefits

The Project will provide regional air quality benefits by reducing Airport-related VMT by over 5 million miles or 10 percent. The addition of 5,000 new on-Airport commercial parking spaces is estimated to decrease drop-off/pick-up travel, reducing overall trips and associated VMT. The Project is expected to provide the following benefits that would directly translate to reductions in emissions:

- Shifting “would-be parkers” from drop-off/pick-up modes to parking;
- Reducing the number of trips associated with “would-be parkers” traveling to and from the Airport;
- Reducing recirculation at the Terminal E curbsides resulting in decreases in on-Airport VMT; and
- Reducing on-Airport emissions related to improved curbside operations at Terminal E, as air passengers shift from drop-off/pick-up modes to parking in the garages.

With the Project, the annual emissions of the ozone pre-cursors nitrogen oxides (NOx) and volatile organic compounds (VOCs) are expected to decrease by 11 percent and 12 percent, respectively, as compared to the No-Build Alternative. These benefits would be achieved in stages, correlating to the availability of additional parking. A portion of the emissions reduction would be realized when the new garage in front of Terminal E is operational in 2022. Additional reductions would be expected when the Economy Garage expansion is operational by the end of 2025, at which point all additional spaces will be built and the full reduction in regional VMT and emissions associated with the “would-be parkers” would occur.

Noise Benefits

The expansion of the Economy Garage is expected to have added noise barrier benefits, in conjunction with the Terminal E Modernization Project, enhancing screening of community and neighborhood recreation areas from aircraft ground noise in the North Apron Area.

3. Construction Period Management

It is expected that construction would take place primarily during the day shift, approximately 7:00 AM to 7:00 PM. The need for nighttime or weekend work would be further determined during construction phasing development. Massport has developed a number of construction mitigation measures and best practices for the Logan Airport Parking Project, including:

- Storage areas for construction materials will be located on-Airport.
- A Draft Soil Management Plan will be developed based upon sub-surface investigations. The plan will outline standards and procedures for identifying and disposing contaminated materials that may be encountered during construction. Soil tracking protocols will be detailed from the point of excavation to designated testing areas and the ultimate disposal site.
- A Draft Stormwater Pollution Prevention Plan will be developed to keep the Airport's stormwater system free of sediment and contaminants during construction. The plan will be incorporated into construction plans, specifications, and contracts.
- A Draft Management Plan for Dewatering, if needed, will be developed to address the requirements for testing, handling, and treatment prior to discharge of contaminated groundwater from dewatering.
- A Draft Health and Safety Plan will be developed to provide the minimum health and safety specifications that contractors must meet during construction including requirements for environmental monitoring, personnel protective equipment, site control and security, and training.
- A Draft Construction Waste Management Plan will be developed for collecting, storing, and handling recyclables.
- Rodent control inspection, monitoring, and treatment will be carried out before, during, and after the completion of all foundation and utility demolition and construction work.
- Construction equipment and materials that are repurposed, reused, or recycled (or contain recycled content) will be prioritized, where feasible, to reduce the Proposed Project’s consumption of virgin natural resources.

As construction progresses, Massport will continue to provide the community with periodic updates on the Project through regularly scheduled community, neighborhood, and other civic meetings. Further, the status of the Project will be reported in upcoming EDRs and ESPRs. The community will be able to report any construction-related concerns in the interim through a construction hotline that Massport will establish and monitor. Concerns will be communicated to construction contractors and subcontractors for resolution in a timely fashion, as appropriate. In cases of an emergency, callers to the hotline will be notified on how to reach key emergency personnel.

Mitigation measures in a number of categories where temporary construction impacts could occur are described below.

Construction Period Surface Transportation Mitigation

Construction traffic mitigation will focus on two issues: 1) minimizing construction-related vehicles on local roadways, and 2) ensuring that all Airport roadway operations are maintained at full capacity to minimize traffic congestion both on- and off-Airport. The specific measures to be taken are noted below:

- All trucks will access the sites by Route lA, Interstate 90, and the main Airport roadways only. Trucks will be prohibited from using local streets unless seeking construction-related access to or from local businesses.
- Truck routes will be specified in contractors' construction specifications.
- Concrete production and batching will occur in existing plants with access via Route lA or Interstate 90. This would reduce an-Airport construction activities and consolidate truck trips to the greatest extent possible.
- Construction workers will be encouraged to use public transportation or shuttle buses from off-Airport parking areas. Specific actions regarding construction worker access are noted below.
    - Massport will encourage construction workers to use Massachusetts Bay Transportation Authority transit services, Logan Express, the water shuttle, and other high-occupancy modes of travel.
    - Construction companies will be encouraged to provide off-Airport parking for their employees and to provide shuttle services from these locations. Massport will encourage contractors to locate off-Airport construction worker parking in areas adjacent to regional arterial roadways to help further minimize traffic on local streets. The employee shuttles will be required to use the Coughlin Bypass road to access the Airport to keep them off neighborhood streets.

Construction Period Air Quality Mitigation

Massport will require all contractors to comply with certain construction guidelines and best management practices that include:

- Construction vehicle/equipment anti-idling;
- Using low- or zero-emissions equipment, where practicable;
- Retrofitting appropriate diesel construction equipment with diesel oxidation catalysts and/or particulate filters;
- Reducing onsite vehicle speeds;
- Reducing exposed erodible surface areas through appropriate materials and equipment staging procedures;
- Covering exposed surface areas with pavement or vegetation in an expeditious manner;

- Stabilizing soil with cover or periodic watering;
- Using covered haul trucks during materials transportation;
- Suspending construction activities during high-wind conditions; and
- Ensuring contractor knowledge of appropriate equipment exhaust and fugitive dust controls.

Construction Period Noise Mitigation

Sound levels from construction activities would be consistent with the City of Boston's noise criteria (even though Massport is not subject to these criteria), no construction noise mitigation is required. Construction equipment, however, will use noise-reduction measures such as:

- Noise control techniques will be used to reduce noise from pile driving at the new garage in front of Terminal E by at least 5 A-weighted decibels (dBA) below their unmitigated levels. These techniques include such measures as enclosing the point of impact for the pile driver; installing an impact cushion between the pile driver and the pile; or requiring the application of dampening (energy-absorbing) material to steel piles. No pile driving is anticipated for the Economy Garage expansion.
- Further noise control options will be evaluated during Project design to define their effectiveness and feasibility. Appropriate operational specifications and performance standards will be incorporated into the construction contract documents. In addition, community noise levels will be monitored during construction to verify compliance with contract specifications and applicable state and local noise regulations.

Construction Period Water Quality Mitigation

Soil disturbance from construction activities creates the potential for water quality impacts from stormwater runoff and erosion. The Project will be required to comply with the requirements of the NPDES General Permit for Stormwater Discharges from Construction Activities. The NPDES permit requires filing a Notice of Intent and preparing a Stormwater Pollution Prevention Plan. As part of the Stormwater Pollution Prevention Plan, an Erosion and Sedimentation Control Program will be put in place to minimize construction phase impacts to adjacent properties and the Boston Harbor. Further, Massport will comply with the provisions of the Massachusetts Contingency Plan.

The following spill prevention measures and sedimentation controls will be deployed throughout the construction phases to prevent pollution from construction equipment and erosion. These controls are provided as recommendations for the site contractor and do not constitute or replace the final Stormwater Pollution Prevention Plan that must be fully implemented by the contractor and owner in compliance with the EPA's NPDES regulations and with Massport's contractor requirements.

- Perimeter barriers such as straw wattles or compost-filled "silt sock" barriers will be placed around upland work areas to trap sediment transported by runoff before it reaches the drainage system or leaves the construction site;
- Existing catch basins within the work sites will be protected with barriers (where appropriate) or silt sacks; and
- Open soil surfaces will be stabilized within 14 days after grading or construction activities have temporarily or permanently ceased.

Coordination with Other On-Airport Construction Activities

Construction activities associated with the new garage in front of Terminal E is expected to occur simultaneous with other on-Airport projects, including Terminal E Modernization and the Terminal C Canopy, Connector, and Roadways Project. To address any unanticipated congestion associated with construction activities, Massport will implement several mitigation measures:

- Develop and facilitate traffic management strategies Airport-wide that are responsive to the aggregate of construction projects and their potential impacts.
- Manage traffic related to construction workers by diverting them to off-Airport locations and requiring contractors to shuttle employees to the job site.
- Coordinate the arrival of large construction equipment among projects and limit their arrival or removal during peak travel hours (both Airport and commuter peaks).
- Develop specific truck routing and/or project staging plans for implementation by the various contractors. It is anticipated that these plans may be developed with input from the contractors directly.

In keeping with Massport's long-standing policy that traffic operations along roadways be maintained to accommodate passenger levels, construction will be staged (and staging modified as necessary) to the maximum extent practicable to avoid disruption to the transportation system or impact to the surrounding environment. The contractor or subcontractor would be responsible for implementing each construction-related measure identified above.

4. Timing and Responsibility for Implementation

All measures will be implemented according to each project element's phased schedule. Massport anticipates first constructing the new garage in front of Terminal E, which would be located on existing short-term parking lots. Construction of this garage is expected to begin in Spring 2020 and be complete in 2022. Construction of the Economy Garage expansion is due to begin in 2023 and be complete by the end of 2025. Non-construction mitigation measures will be implemented as part of the design or operation of the Proposed Project elements. Responsibilities for implementation are identified in Table 1 above.

5. Additional Ground Access Improvement, Trip Reduction, and Emissions Reduction Initiatives

In addition to those measures discussed above, Massport will undertake and implement the below measures:

- Prior to commencement of construction of the Parking Project, Massport will advance the electrification of ground service equipment, pursuant to which all ground service equipment will be replaced no later than the end of 2027, where commercially available electric alternatives are available (with a limited deferral for categories of equipment where no commercially available electric alternatives are available). For categories of equipment for which no electric or other zero emission alternative is commercially available by the end of 2027, such equipment will be replaced in those categories within two years of such equipment becoming commercially available (provided the equipment being replaced is at least eight years old). Massport may, in the alternative, develop a phased schedule in which certain categories are implemented earlier than 2027 and some are deployed later than 2027, so long as 2027 is the mean deployment date at Logan Airport.

  Massport will achieve the following targets for electrification of ground service equipment: at least 9 percent by the beginning of Parking Project construction; at least 12 percent by the end of construction of the first parking structure (new garage in front of Terminal E); and at least 24 percent by the end of construction of the second parking structure (Economy Garage expansion). Moreover, Massport will ensure that at least 60 percent of commercial aircraft taxiing for re-positioning will be done by electric tugs by 2027.

- Massport will increase its Logan Express capacity, measured in available seats, by 10 percent over the number of seats available in May 2017.

- Massport will implement several measures to promote the use of electric vehicles among the combined fleet of taxi, livery, and transportation network company (TNC) vehicles:
    - Massport will provide high-speed electric vehicle charging stations at all taxi, livery, and TNC pools at Logan Airport, so that 150 percent of demand for charging stations is available at all pools at all times at no cost to the user (this demand will be measured as no more than 66.667 percent of electric vehicle charging stations in use at any time).
    - Massport will provide taxi and TNC queue priority to electric vehicles (second only to vehicles with at least three passengers), subject to negotiations with the relevant companies.

Appendix D

- Federal Aviation Administration Terminal Area Forecast

This Page Intentionally Left Blank.

FAA Terminal Area Forecast, Issued January 2018

Boston Logan (BOS)

				AIRCRAFT OPERATIONS				
	Enplanements			Itinerant Operations				
Fiscal Year	**Air Carrier**	**Commuter**	**Total**	**Air Carrier**	**Air Taxi & Commuter**	**GA**	**Military**	**Total Ops**
REGION:ANE **STATE:**MA **LOCID:**BOS								
CITY:BOSTON **AIRPORT:**GENERAL EDWARD LAWRENCE LOGAN INTL								
2017*	17,371,668	1,149,970	18,521,638	315,694	69,742	14,869	435	400,740
2018*	18,781,199	1,268,572	20,049,771	344,372	64,977	14,583	435	424,367
2019*	19,384,174	1,306,063	20,690,237	355,747	64,706	14,613	435	435,501
2020*	19,929,816	1,340,355	21,270,171	366,265	64,026	14,643	435	445,369
2021*	20,442,772	1,372,738	21,815,510	376,685	62,634	14,673	435	454,427
2022*	20,961,924	1,405,380	22,367,304	387,375	61,055	14,703	435	463,568
2023*	21,481,078	1,438,080	22,919,158	397,108	60,651	14,733	435	472,927
2024*	22,000,642	1,470,793	23,471,435	405,943	61,347	14,763	435	482,488
2025*	22,522,475	1,503,570	24,026,045	414,616	62,286	14,793	435	492,130
2026*	23,056,223	1,536,865	24,593,088	423,487	63,246	14,823	435	501,991
2027*	23,609,086	1,570,970	25,180,056	432,689	64,247	14,853	435	512,224
2028*	24,182,566	1,606,039	25,788,605	442,243	65,281	14,883	435	522,842
2029*	24,769,961	1,641,732	26,411,693	452,037	66,345	14,914	435	533,731
2030*	25,360,817	1,677,578	27,038,395	461,876	67,413	14,945	435	544,669
2031*	25,957,909	1,713,492	27,671,401	471,812	68,486	14,976	435	555,709
2032*	26,550,671	1,749,018	28,299,689	481,646	69,547	15,007	435	566,635
2033*	27,136,349	1,784,086	28,920,435	491,337	70,596	15,038	435	577,406
2034*	27,741,250	1,820,185	29,561,435	501,379	71,687	15,069	435	588,570
2035*	28,360,739	1,857,035	30,217,774	511,675	72,809	15,100	435	600,019
2036*	28,988,202	1,894,241	30,882,443	522,107	73,946	15,131	435	611,619
2037*	29,614,955	1,931,351	31,546,306	532,501	75,076	15,162	435	623,174
2038*	30,251,336	1,968,898	32,220,234	543,079	76,227	15,193	435	634,934
2039*	30,899,922	2,007,000	32,906,922	553,868	77,402	15,224	435	646,929
2040*	31,557,666	2,045,629	33,603,295	564,820	78,596	15,255	435	659,106
2041*	32,222,951	2,084,512	34,307,463	575,902	79,803	15,286	435	671,426
2042*	32,887,725	2,123,223	35,010,948	586,962	81,006	15,317	435	683,720
2043*	33,567,723	2,162,626	35,730,349	598,287	82,239	15,348	435	696,309
2044*	34,257,151	2,202,449	36,459,600	609,778	83,490	15,379	435	709,082
2045*	34,958,459	2,242,835	37,201,294	621,475	84,764	15,411	435	722,085

Source: https://taf.faa.gov/Home/RunReport

Appendix E

- Surface Transportation Technical Appendix
  - Traffic Data
  - Crash Data
  - Intersection Analysis
  - QATAR Analysis

This Page Intentionally Left Blank.

Traffic Data

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 1
Location: Logan Airport, MA
Street 1: Service Road
Street 2: Prescott Street
Count Date: 8/13/2018
Day of Week: Monday
Weather: Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TOTAL (CARS & TRUCKS)

	Service Road Northbound				Service Road Southbound				Eastbound				Prescott Street Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
5:00 AM	0	0	31	20	0	16	16	0	0	0	0	0	0	8	0	5
5:15 AM	0	0	32	21	0	15	21	0	0	0	0	0	0	7	0	6
5:30 AM	0	0	35	19	0	14	28	0	0	0	0	0	0	6	0	7
5:45 AM	0	0	36	21	0	13	32	0	0	0	0	0	0	7	0	8
6:00 AM	0	0	39	20	0	11	44	0	0	0	0	0	0	5	0	9
6:15 AM	0	0	40	25	0	12	51	0	0	0	0	0	0	9	0	10
6:30 AM	0	0	38	29	0	10	46	0	0	0	0	0	0	12	0	9
6:45 AM	0	0	37	26	0	9	42	0	0	0	0	0	0	11	0	8

	Service Road Northbound				Service Road Southbound				Eastbound				Prescott Street Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
4:00 PM	0	0	62	10	0	4	55	0	0	0	0	0	0	11	0	11
4:15 PM	0	0	64	12	0	7	58	0	0	0	0	0	0	13	0	12
4:30 PM	0	0	66	11	0	5	53	0	0	0	0	0	0	12	0	11
4:45 PM	0	0	72	10	0	6	46	0	0	0	0	0	0	11	0	10
5:00 PM	0	0	75	9	0	5	41	0	0	0	0	0	0	13	0	12
5:15 PM	0	0	68	11	0	7	33	0	0	0	0	0	0	14	0	11
5:30 PM	0	0	63	10	0	6	37	0	0	0	0	0	0	12	0	10
5:45 PM	0	0	58	11	0	7	32	0	0	0	0	0	0	13	0	8
6:00 PM	0	0	52	12	0	8	36	0	0	0	0	0	0	11	0	9
6:15 PM	0	0	53	13	0	9	32	0	0	0	0	0	0	12	0	10
6:30 PM	0	0	55	14	0	10	36	0	0	0	0	0	0	11	0	8
6:45 PM	0	0	56	15	0	12	38	0	0	0	0	0	0	12	0	7
7:00 PM	0	0	55	16	0	13	44	0	0	0	0	0	0	10	0	6
7:15 PM	0	0	53	12	0	15	47	0	0	0	0	0	0	11	0	7
7:30 PM	0	0	48	7	0	16	42	0	0	0	0	0	0	12	0	5
7:45 PM	0	0	45	6	0	14	39	0	0	0	0	0	0	11	0	6

AM PEAK HOUR 6:00 AM to 7:00 AM	Service Road Northbound				Service Road Southbound				Eastbound				Prescott Street Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
	0	**0**	**154**	**100**	**0**	**42**	**183**	**0**	**0**	**0**	**0**	**0**	**0**	**37**	**0**	**36**
PHF	**0.95**				**0.89**				**0.00**				**0.87**			
HV %	**0.0%**	**0.0%**	**1.3%**	**3.0%**	**0.0%**	**11.9%**	**2.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**2.7%**	**0.0%**	**13.9%**

PM PEAK HOUR 6:30 PM to 7:30 PM	Service Road Northbound				Service Road Southbound				Eastbound				Prescott Street Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
	0	**0**	**219**	**57**	**0**	**50**	**165**	**0**	**0**	**0**	**0**	**0**	**0**	**44**	**0**	**28**
PHF	**0.97**				**0.87**				**0.00**				**0.95**			
HV %	**0.0%**	**0.0%**	**1.8%**	**1.8%**	**0.0%**	**6.0%**	**1.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**7.1%**

8/17/2018, 5:56 PM, 236_046_TMC_Loc 1

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 1
Location: Logan Airport, MA
Street 1: Service Road
Street 2: Prescott Street
Count Date: 8/13/2018
Day of Week: Monday
Weather: Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TRUCKS

	Service Road Northbound				Service Road Southbound				Eastbound				Prescott Street Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
5:00 AM	0	0	2	0	0	2	1	0	0	0	0	0	0	0	0	0
5:15 AM	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	1
5:30 AM	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1
5:45 AM	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
6:00 AM	0	0	0	2	0	1	2	0	0	0	0	0	0	0	0	1
6:15 AM	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	2
6:30 AM	0	0	1	0	0	1	1	0	0	0	0	0	0	1	0	1
6:45 AM	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	1

	Service Road Northbound				Service Road Southbound				Eastbound				Prescott Street Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
4:00 PM	0	0	2	0	0	1	1	0	0	0	0	0	0	0	0	1
4:15 PM	0	0	1	0	0	2	1	0	0	0	0	0	0	0	0	3
4:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4:45 PM	0	0	1	0	0	0	2	0	0	0	0	0	0	1	0	1
5:00 PM	0	0	2	0	0	1	1	0	0	0	0	0	0	0	0	1
5:15 PM	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	2
5:30 PM	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	1
5:45 PM	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	2
6:00 PM	0	0	4	0	0	1	3	0	0	0	0	0	0	0	0	0
6:15 PM	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
6:30 PM	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1
6:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00 PM	0	0	3	1	0	1	1	0	0	0	0	0	0	0	0	0
7:15 PM	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
7:30 PM	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
7:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

AM PEAK HOUR 6:00 AM to 7:00 AM	Service Road Northbound				Service Road Southbound				Eastbound				Prescott Street Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
	0	**0**	**2**	**3**	**0**	**5**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**5**
PHF	**0.63**				**0.75**				**0.00**				**0.75**			

PM PEAK HOUR 6:00 PM to 7:00 PM	Service Road Northbound				Service Road Southbound				Eastbound				Prescott Street Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
	0	**0**	**6**	**0**	**0**	**2**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**
PHF	**0.38**				**0.38**				**0.00**				**0.50**			

8/17/2018, 5:56 PM, 236_046_TMC_Loc 1

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 1
Location:	Logan Airport, MA
Street 1:	Service Road
Street 2:	Prescott Street
Count Date:	8/13/2018
Day of Week:	Monday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

PEDESTRIANS & BICYCLES

	Service Road Northbound					Service Road Southbound					Eastbound					Prescott Street Westbound				
Start Time	Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED	
5:00 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	1	
5:15 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	3	
5:30 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:45 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	1	
6:00 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:15 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	1	
6:30 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	2	
6:45 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	1	

	Service Road Northbound					Service Road Southbound					Eastbound					Prescott Street Westbound				
Start Time	Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED	
4:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
4:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
4:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	1	
4:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	1	
5:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	1	
7:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
7:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	1	
7:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
7:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	

AM PEAK HOUR[1] 6:00 AM to 7:00 AM	Service Road Northbound					Service Road Southbound					Eastbound					Prescott Street Westbound				
	Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED	
	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	4	

PM PEAK HOUR[1] 6:30 PM to 7:30 PM	Service Road Northbound					Service Road Southbound					Eastbound					Prescott Street Westbound				
	Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED	
	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	2	

[1] *Peak hours corresponds to vehicular peak hours.*

8/17/2018, 5:56 PM, 236_046_TMC_Loc 1

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 2
Location:	Logan Airport, MA
Street 1:	Service Road
Street 2:	Cottage Street
Count Date:	8/13/2018
Day of Week:	Monday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TOTAL (CARS & TRUCKS)

	Service Road Northbound				Service Road Southbound				Service Road (Authorized Vehicles Only) Eastbound				Cottage Street Westbound			
Start Time	U-Turn	Hard Left	Thru	Right	U-Turn	Left	Thru	Soft Right	Left	Thru	Right	Hard Right	U-Turn	Left	Soft Left	Right
5:00 AM	0	1	49	1	0	0	24	0	0	0	0	0	0	0	0	2
5:15 AM	0	2	52	2	0	0	27	1	0	0	0	0	0	0	0	1
5:30 AM	0	3	53	2	0	0	32	2	0	0	0	0	0	0	0	1
5:45 AM	0	4	57	3	0	0	37	2	0	0	0	0	0	0	0	0
6:00 AM	0	5	59	3	0	0	48	1	0	0	0	0	0	0	0	0
6:15 AM	0	4	64	2	0	0	58	2	0	0	0	0	0	0	0	1
6:30 AM	0	5	67	3	0	0	56	2	0	0	2	0	0	1	0	0
6:45 AM	0	4	63	2	0	0	52	1	0	0	0	0	0	0	0	0

	Service Road Northbound				Service Road Southbound				Service Road (Authorized Vehicles Only) Eastbound				Cottage Street Westbound			
Start Time	U-Turn	Hard Left	Thru	Right	U-Turn	Left	Thru	Soft Right	Left	Thru	Right	Hard Right	U-Turn	Left	Soft Left	Right
4:00 PM	0	13	70	3	0	0	62	4	0	0	0	0	0	0	0	2
4:15 PM	0	12	74	3	0	1	65	5	0	0	1	0	0	0	0	2
4:30 PM	0	14	76	2	0	0	60	5	0	0	1	0	0	0	0	1
4:45 PM	0	12	81	2	0	0	53	4	0	0	0	0	0	0	0	1
5:00 PM	0	13	84	2	0	0	49	5	0	0	0	1	0	0	0	0
5:15 PM	0	12	78	3	0	0	44	3	0	0	1	0	0	0	0	1
5:30 PM	0	10	71	2	0	0	45	4	1	0	0	0	0	0	0	1
5:45 PM	0	9	67	3	0	0	43	2	0	0	1	0	0	0	0	2
6:00 PM	0	7	62	3	0	0	44	3	0	0	2	1	0	0	0	2
6:15 PM	0	8	65	2	0	0	42	2	1	0	0	1	0	0	0	0
6:30 PM	0	6	67	3	0	0	44	3	1	0	1	1	0	0	0	1
6:45 PM	0	5	70	3	0	0	46	4	0	0	2	0	0	0	0	1
7:00 PM	0	4	71	2	0	0	49	5	0	0	0	0	0	0	0	0
7:15 PM	0	5	63	3	0	1	51	6	1	0	1	1	0	0	0	1
7:30 PM	0	4	53	2	0	0	49	5	1	0	1	0	0	1	0	1
7:45 PM	0	3	51	2	0	0	47	3	0	0	0	0	0	0	0	0

AM PEAK HOUR 6:00 AM to 7:00 AM	Service Road Northbound				Service Road Southbound				Service Road (Authorized Vehicles Only) Eastbound				Cottage Street Westbound			
	U-Turn	Hard Left	Thru	Right	U-Turn	Left	Thru	Soft Right	Left	Thru	Right	Hard Right	U-Turn	Left	Soft Left	Right
	0	**18**	**253**	**10**	**0**	**0**	**214**	**6**	**0**	**0**	**2**	**0**	**0**	**1**	**0**	**1**
PHF	**0.94**				**0.92**				**0.25**				**0.50**			
HV %	**0.0%**	**0.0%**	**2.4%**	**0.0%**	**0.0%**	**0.0%**	**2.3%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

PM PEAK HOUR 6:30 PM to 7:30 PM	Service Road Northbound				Service Road Southbound				Service Road (Authorized Vehicles Only) Eastbound				Cottage Street Westbound			
	U-Turn	Hard Left	Thru	Right	U-Turn	Left	Thru	Soft Right	Left	Thru	Right	Hard Right	U-Turn	Left	Soft Left	Right
	0	**20**	**271**	**11**	**0**	**1**	**190**	**18**	**2**	**0**	**4**	**2**	**0**	**0**	**0**	**3**
PHF	**0.97**				**0.90**				**0.67**				**0.75**			
HV %	**0.0%**	**0.0%**	**1.8%**	**0.0%**	**0.0%**	**0.0%**	**1.1%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

8/17/2018, 6:08 PM, 236_046_TMC_Loc 2

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 2
Location: Logan Airport, MA
Street 1: Service Road
Street 2: Cottage Street
Count Date: 8/13/2018
Day of Week: Monday
Weather: Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TRUCKS

	Service Road Northbound				Service Road Southbound				Service Road (Authorized Vehicles Only) Eastbound				Cottage Street Westbound			
Start Time	U-Turn	Hard Left	Thru	Right	U-Turn	Left	Thru	Soft Right	Left	Thru	Right	Hard Right	U-Turn	Left	Soft Left	Right
5:00 AM	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0
5:15 AM	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
5:30 AM	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0
5:45 AM	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
6:00 AM	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0
6:15 AM	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
6:30 AM	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0
6:45 AM	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0

	Service Road Northbound				Service Road Southbound				Service Road (Authorized Vehicles Only) Eastbound				Cottage Street Westbound			
Start Time	U-Turn	Hard Left	Thru	Right	U-Turn	Left	Thru	Soft Right	Left	Thru	Right	Hard Right	U-Turn	Left	Soft Left	Right
4:00 PM	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0
4:15 PM	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
4:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:45 PM	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0
5:00 PM	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0
5:15 PM	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
5:30 PM	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5:45 PM	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
6:00 PM	0	0	3	0	0	0	3	0	0	0	0	0	0	0	0	0
6:15 PM	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
6:30 PM	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
6:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00 PM	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0
7:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

AM PEAK HOUR	Service Road Northbound				Service Road Southbound				Service Road (Authorized Vehicles Only) Eastbound				Cottage Street Westbound			
6:00 AM to	U-Turn	Hard Left	Thru	Right	U-Turn	Left	Thru	Soft Right	Left	Thru	Right	Hard Right	U-Turn	Left	Soft Left	Right
7:00 AM	**0**	**0**	**6**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
PHF	**0.75**				**0.63**				**0.00**				**0.00**			

PM PEAK HOUR	Service Road Northbound				Service Road Southbound				Service Road (Authorized Vehicles Only) Eastbound				Cottage Street Westbound			
6:00 PM to	U-Turn	Hard Left	Thru	Right	U-Turn	Left	Thru	Soft Right	Left	Thru	Right	Hard Right	U-Turn	Left	Soft Left	Right
7:00 PM	**0**	**0**	**6**	**0**	**0**	**0**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
PHF	**0.50**				**0.33**				**0.00**				**0.00**			

8/17/2018, 6:08 PM, 236_046_TMC_Loc 2

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 2
Location:	Logan Airport, MA
Street 1:	Service Road
Street 2:	Cottage Street
Count Date:	8/13/2018
Day of Week:	Monday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

PEDESTRIANS & BICYCLES

	Service Road Northbound					Service Road Southbound					Service Road (Authorized Vehicles Only) Eastbound					Cottage Street Westbound				
Start Time	Hard Left	Thru	Right	PED		Left	Thru	Soft Right	PED		Thru	Right	Hard Right	PED		Left	Soft Left	Right	PED	
5:00 AM	0	0	0	0		0	0	0	1		0	0	0	1		0	0	0	0	
5:15 AM	0	0	0	1		0	0	0	3		0	0	0	3		0	0	0	1	
5:30 AM	0	0	0	1		0	0	0	0		0	0	0	0		0	0	0	0	
5:45 AM	0	0	0	0		0	0	0	1		0	0	0	1		0	0	0	0	
6:00 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:15 AM	0	0	0	0		0	0	0	1		0	0	0	1		0	0	0	0	
6:30 AM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	1	
6:45 AM	0	0	0	1		0	0	0	6		0	0	0	6		0	0	0	0	

	Service Road Northbound					Service Road Southbound					Service Road (Authorized Vehicles Only) Eastbound					Cottage Street Westbound				
Start Time	Hard Left	Thru	Right	PED		Left	Thru	Soft Right	PED		Thru	Right	Hard Right	PED		Left	Soft Left	Right	PED	
4:00 PM	0	0	0	0		0	0	0	2		0	0	0	2		0	0	0	1	
4:15 PM	0	0	0	0		0	0	0	3		0	0	0	3		0	0	0	1	
4:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
4:45 PM	0	0	0	0		0	0	0	2		0	0	0	2		0	0	0	1	
5:00 PM	0	0	0	1		0	0	0	1		0	0	0	1		0	0	0	0	
5:15 PM	0	0	0	0		0	0	0	2		0	0	0	2		0	0	0	0	
5:30 PM	0	0	0	0		0	0	0	2		0	0	0	2		0	0	0	2	
5:45 PM	0	0	0	0		0	0	0	1		0	0	0	1		0	0	0	0	
6:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:30 PM	0	0	0	0		0	0	0	2		0	0	0	2		0	0	0	1	
6:45 PM	0	0	0	0		0	0	0	1		0	0	0	1		0	0	0	0	
7:00 PM	0	0	0	1		0	0	0	2		0	0	0	2		0	0	0	1	
7:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
7:30 PM	0	0	0	0		0	0	0	1		0	0	0	1		0	0	0	0	
7:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	

AM PEAK HOUR[1] 6:00 AM to 7:00 AM	Service Road Northbound					Service Road Southbound					Service Road (Authorized Vehicles Only) Eastbound					Cottage Street Westbound				
	Hard Left	Thru	Right	PED		Left	Thru	Soft Right	PED		Thru	Right	Hard Right	PED		Left	Soft Left	Right	PED	
	0	0	0	1		0	0	0	7		0	0	0	8		0	0	0	1	

PM PEAK HOUR[1] 6:30 PM to 7:30 PM	Service Road Northbound					Service Road Southbound					Service Road (Authorized Vehicles Only) Eastbound					Cottage Street Westbound				
	Hard Left	Thru	Right	PED		Left	Thru	Soft Right	PED		Thru	Right	Hard Right	PED		Left	Soft Left	Right	PED	
	0	0	0	1		0	0	0	5		0	0	0	5		0	0	0	2	

[1] *Peak hours corresponds to vehicular peak hours.*

8/17/2018, 6:08 PM, 236_046_TMC_Loc 2

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 3
Location: Logan Airport, MA
Street 1: Service Road
Street 2: Hotel Drive
Count Date: 8/13/2018
Day of Week: Monday
Weather: Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TOTAL (CARS & TRUCKS)

	Hotel Drive Northbound				Service Road Southbound				Service Road Eastbound				Airport Road Off-Ramp Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
5:00 AM	0	25	20	0	0	0	30	0	0	10	0	9	0	15	15	7
5:15 AM	0	28	19	0	0	0	32	0	0	11	0	14	0	14	16	8
5:30 AM	0	31	21	0	0	0	31	1	0	11	0	18	0	16	19	9
5:45 AM	0	35	22	0	0	0	30	1	0	12	0	24	0	17	22	10
6:00 AM	0	39	21	0	0	0	32	0	0	11	0	29	0	24	26	12
6:15 AM	0	45	28	0	0	0	31	1	0	10	0	36	0	30	29	13
6:30 AM	1	50	34	0	0	0	30	2	0	8	0	43	0	29	28	11
6:45 AM	0	47	31	0	0	0	32	1	0	9	0	38	0	27	26	12

	Hotel Drive Northbound				Service Road Southbound				Service Road Eastbound				Airport Road Off-Ramp Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
4:00 PM	0	76	30	0	0	0	76	7	0	17	0	12	0	36	24	9
4:15 PM	0	79	29	0	0	0	79	8	0	16	0	16	0	40	27	10
4:30 PM	0	81	28	0	0	0	78	7	0	14	0	20	0	37	25	12
4:45 PM	0	85	29	0	0	0	77	5	0	12	0	26	0	33	23	14
5:00 PM	0	88	27	0	0	0	76	4	0	10	0	31	0	30	21	16
5:15 PM	0	84	28	0	0	0	78	2	0	13	0	33	0	27	18	17
5:30 PM	0	80	29	0	0	0	75	3	0	11	0	34	0	28	19	15
5:45 PM	0	76	30	0	0	0	70	3	0	12	0	36	0	29	20	12
6:00 PM	1	71	31	0	0	0	67	2	0	10	0	38	0	31	21	11
6:15 PM	0	74	28	0	0	0	62	4	0	12	0	40	0	33	19	9
6:30 PM	0	75	25	0	0	0	63	5	0	13	0	39	0	28	17	10
6:45 PM	0	79	23	0	0	0	61	6	0	16	0	41	0	23	15	11
7:00 PM	0	81	20	0	0	0	64	8	0	18	0	40	0	18	14	10
7:15 PM	0	70	24	0	0	0	63	10	0	15	0	44	0	12	12	8
7:30 PM	0	58	27	0	0	0	62	9	0	17	0	47	0	14	13	9
7:45 PM	0	55	25	0	0	0	60	7	0	16	0	45	0	13	11	8

AM PEAK HOUR 6:00 AM to 7:00 AM	Hotel Drive Northbound				Service Road Southbound				Service Road Eastbound				Airport Road Off-Ramp Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
	1	**181**	**114**	**0**	**0**	**0**	**125**	**4**	**0**	**38**	**0**	**146**	**0**	**110**	**109**	**48**
PHF	**0.87**				**0.98**				**0.90**				**0.93**			
HV %	**0.0%**	**2.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**2.6%**	**0.0%**	**2.1%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

PM PEAK HOUR 6:00 PM to 7:00 PM	Hotel Drive Northbound				Service Road Southbound				Service Road Eastbound				Airport Road Off-Ramp Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
	1	**299**	**107**	**0**	**0**	**0**	**253**	**17**	**0**	**51**	**0**	**158**	**0**	**115**	**72**	**41**
PHF	**0.99**				**0.98**				**0.92**				**0.90**			
HV %	**0.0%**	**2.3%**	**1.9%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**1.3%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

8/17/2018, 6:18 PM, 236_046_TMC_Loc 3

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 3
Location: Logan Airport, MA
Street 1: Service Road
Street 2: Hotel Drive
Count Date: 8/13/2018
Day of Week: Monday
Weather: Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TRUCKS

	Hotel Drive Northbound				Service Road Southbound				Service Road Eastbound				Airport Road Off-Ramp Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
5:00 AM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15 AM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:30 AM	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
5:45 AM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:00 AM	0	2	0	0	0	0	0	0	0	1	0	1	0	0	0	0
6:15 AM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:30 AM	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
6:45 AM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Hotel Drive Northbound				Service Road Southbound				Service Road Eastbound				Airport Road Off-Ramp Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
4:00 PM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:15 PM	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0
4:30 PM	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:45 PM	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
5:00 PM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15 PM	0	3	1	0	0	0	0	0	0	0	0	1	0	0	0	0
5:30 PM	0	4	0	0	0	0	0	0	0	0	0	1	0	0	0	0
5:45 PM	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0
6:00 PM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:15 PM	0	4	2	0	0	0	0	0	0	0	0	1	0	0	0	0
6:30 PM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:45 PM	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
7:00 PM	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0
7:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:30 PM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

AM PEAK HOUR 6:00 AM to 7:00 AM	Hotel Drive Northbound				Service Road Southbound				Service Road Eastbound				Airport Road Off-Ramp Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
	0	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**3**	**0**	**0**	**0**	**0**
PHF	**0.50**				**0.00**				**0.50**				**0.00**			

PM PEAK HOUR 6:15 PM to 7:15 PM	Hotel Drive Northbound				Service Road Southbound				Service Road Eastbound				Airport Road Off-Ramp Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
	0	**9**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**
PHF	**0.46**				**0.00**				**0.75**				**0.00**			

8/17/2018, 6:18 PM, 236_046_TMC_Loc 3

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 3
Location: Logan Airport, MA
Street 1: Service Road
Street 2: Hotel Drive
Count Date: 8/13/2018
Day of Week: Monday
Weather: Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

PEDESTRIANS & BICYCLES

	Hotel Drive Northbound					Service Road Southbound					Service Road Eastbound					Airport Road Off-Ramp Westbound				
Start Time	Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED	
5:00 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:15 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:30 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:45 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:00 AM	0	0	0	0		0	0	0	1		0	0	0	0		0	0	0	0	
6:15 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:30 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:45 AM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	

	Hotel Drive Northbound					Service Road Southbound					Service Road Eastbound					Airport Road Off-Ramp Westbound				
Start Time	Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED	
4:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
4:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
4:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
4:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
7:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	2	
7:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
7:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
7:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	

AM PEAK HOUR[1]	Hotel Drive Northbound					Service Road Southbound					Service Road Eastbound					Airport Road Off-Ramp Westbound				
6:00 AM to	Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED	
7:00 AM	0	0	0	0		0	0	0	1		0	0	0	0		0	0	0	0	

PM PEAK HOUR[1]	Hotel Drive Northbound					Service Road Southbound					Service Road Eastbound					Airport Road Off-Ramp Westbound				
6:00 PM to	Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED		Left	Thru	Right	PED	
7:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	

[1] *Peak hours corresponds to vehicular peak hours.*

8/17/2018, 6:18 PM, 236_046_TMC_Loc 3

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 4
Location:	Logan Airport, MA
Street 1:	Term E Arr. Entry Ramp
Street 2:	Term E Arr. Entry, C-E Conn Rd
Count Date:	8/14/2018
Day of Week:	Tuesday
Weather:	Mostly Cloudy w/ Showers, 80°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TOTAL (CARS & TRUCKS)

	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
Start Time	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	35	25	0	0	0	0	0	107	10	0	0	0	0	0
3:15 PM	0	0	37	24	0	0	0	0	0	104	11	0	0	0	0	0
3:30 PM	0	0	39	22	0	0	0	0	0	98	12	0	0	0	0	0
3:45 PM	0	0	42	21	0	0	0	0	0	96	14	0	0	0	0	0
4:00 PM	0	0	44	20	0	0	0	0	0	92	15	0	0	0	0	0
4:15 PM	0	0	47	17	0	0	0	0	0	83	14	0	0	0	0	0
4:30 PM	0	0	49	14	0	0	0	0	0	73	13	0	0	0	0	0
4:45 PM	0	0	52	12	0	0	0	0	0	68	12	0	0	0	0	0
5:00 PM	0	0	54	8	0	0	0	0	0	61	10	0	0	0	0	0
5:15 PM	0	0	49	11	0	0	0	0	0	67	11	0	0	0	0	0
5:30 PM	0	0	43	9	0	0	0	0	0	72	12	0	0	0	0	0
5:45 PM	0	0	38	10	0	0	0	0	0	77	14	0	0	0	0	0
6:00 PM	0	0	32	8	0	0	0	0	0	80	13	0	0	0	0	0
6:15 PM	0	0	35	13	0	0	0	0	0	84	16	0	0	0	0	0
6:30 PM	0	0	37	17	0	0	0	0	0	87	19	0	0	0	0	0
6:45 PM	0	0	39	26	0	0	0	0	0	92	22	0	0	0	0	0
7:00 PM	0	0	41	34	0	0	0	0	0	96	25	0	0	0	0	0
7:15 PM	0	0	40	33	0	0	0	0	0	102	22	0	0	0	0	0
7:30 PM	0	0	38	31	0	0	0	0	0	105	19	0	0	0	0	0
7:45 PM	0	0	36	30	0	0	0	0	0	110	18	0	0	0	0	0
8:00 PM	0	0	34	28	0	0	0	0	0	112	16	0	0	0	0	0
8:15 PM	0	0	35	28	0	0	0	0	0	111	17	0	0	0	0	0
8:30 PM	0	0	36	27	0	0	0	0	0	108	15	0	0	0	0	0
8:45 PM	0	0	33	24	0	0	0	0	0	102	14	0	0	0	0	0

PM PEAK HOUR 4:00 PM to 5:00 PM	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
	0	**0**	**192**	**63**	**0**	**0**	**0**	**0**	**0**	**316**	**54**	**0**	**0**	**0**	**0**	**0**
PHF	**1.00**				**0.00**				**0.86**				**0.00**			
HV %	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

8/17/2018, 6:25 PM, 236_046_TMC_Loc 4 Tuesday

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 4
Location: Logan Airport, MA
Street 1: Term E Arr. Entry Ramp
Street 2: Term E Arr. Entry, C-E Conn Rd
Count Date: 8/14/2018
Day of Week: Tuesday
Weather: Mostly Cloudy w/ Showers, 80°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TRUCKS

	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
Start Time	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PM PEAK HOUR 4:00 PM to 5:00 PM	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
PHF	**0.00**				**0.00**				**0.00**				**0.00**			

8/17/2018, 6:25 PM, 236_046_TMC_Loc 4 Tuesday

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 4
Location: Logan Airport, MA
Street 1: Term E Arr. Entry Ramp
Street 2: Term E Arr. Entry, C-E Conn Rd
Count Date: 8/14/2018
Day of Week: Tuesday
Weather: Mostly Cloudy w/ Showers, 80°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

PEDESTRIANS & BICYCLES

	C-E Connecting Road Northbound					Terminal E Arrival Southbound					Terminal E Arrival Entry Ramp Northeastbound					Terminal E Arrival Southeastbound				
Start Time	Hard Left	Soft Left	Thru	PED		Thru	Soft Right	Right	PED		Left	Soft Left	Hard Right	PED		Left	Thru	Right	PED	
3:00 PM	0	0	0	0		0	0	0	1		0	0	0	0		0	0	0	0	
3:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
3:30 PM	0	0	0	0		0	0	0	0		0	0	0	2		0	0	0	0	
3:45 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
4:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
4:15 PM	0	0	0	0		0	0	0	1		0	0	0	5		0	0	0	0	
4:30 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	1	
4:45 PM	0	0	0	0		0	0	0	0		0	0	0	2		0	0	0	0	
5:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	1	
5:30 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
5:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:00 PM	0	0	0	0		0	0	0	2		0	0	0	1		0	0	0	0	
6:15 PM	0	0	0	0		0	0	0	0		0	0	0	3		0	0	0	0	
6:30 PM	0	0	0	2		0	0	0	1		0	0	0	0		0	0	0	2	
6:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
7:00 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
7:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
7:30 PM	0	0	0	0		0	0	0	1		0	0	0	0		0	0	0	0	
7:45 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
8:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
8:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
8:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
8:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	

PM PEAK HOUR[1] 4:00 PM to 5:00 PM	C-E Connecting Road Northbound					Terminal E Arrival Southbound					Terminal E Arrival Entry Ramp Northeastbound					Terminal E Arrival Southeastbound				
	Hard Left	Soft Left	Thru	PED		Thru	Soft Right	Right	PED		Left	Soft Left	Hard Right	PED		Left	Thru	Right	PED	
	0	0	0	0		0	0	0	1		0	0	0	8		0	0	0	1	

[1] *Peak hours corresponds to vehicular peak hours.*

8/17/2018, 6:25 PM, 236_046_TMC_Loc 4 Tuesday

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 4
Location:	Logan Airport, MA
Street 1:	Term E Arr. Entry Ramp
Street 2:	Term E Arr. Entry, C-E Conn Rd
Count Date:	8/13/2018
Day of Week:	Monday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TOTAL (CARS & TRUCKS)

	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
Start Time	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	58	17	0	0	0	0	0	128	32	0	0	0	0	0
3:15 PM	0	0	61	16	0	0	0	0	0	126	33	0	0	0	0	0
3:30 PM	0	0	63	15	0	0	0	0	0	121	34	0	0	0	0	0
3:45 PM	0	0	67	15	0	0	0	0	0	119	36	0	0	0	0	0
4:00 PM	0	0	69	14	0	0	0	0	0	115	37	0	0	0	0	0
4:15 PM	0	0	66	13	0	0	0	0	0	110	34	0	0	0	0	0
4:30 PM	0	0	61	12	0	0	0	0	0	103	31	0	0	0	0	0
4:45 PM	0	0	56	13	0	0	0	0	0	97	27	0	0	0	0	0
5:00 PM	0	0	50	11	0	0	0	0	0	89	23	0	0	0	0	0
5:15 PM	0	0	46	12	0	0	0	0	0	86	26	0	0	0	0	0
5:30 PM	0	0	42	10	0	0	0	0	0	81	24	0	0	0	0	0
5:45 PM	0	0	37	11	0	0	0	0	0	77	25	0	0	0	0	0
6:00 PM	0	0	31	9	0	0	0	0	0	72	23	0	0	0	0	0
6:15 PM	0	0	34	15	0	0	0	0	0	82	26	0	0	0	0	0
6:30 PM	0	0	36	20	0	0	0	0	0	90	29	0	0	0	0	0
6:45 PM	0	0	39	25	0	0	0	0	0	105	33	0	0	0	0	0
7:00 PM	0	0	42	29	0	0	0	0	0	117	37	0	0	0	0	0
7:15 PM	0	0	36	36	0	0	0	0	0	121	35	0	0	0	0	0
7:30 PM	0	0	29	42	0	0	0	0	0	123	36	0	0	0	0	0
7:45 PM	0	0	22	50	0	0	0	0	0	126	35	0	0	0	0	0
8:00 PM	0	0	15	57	0	0	0	0	0	127	37	0	0	0	0	0
8:15 PM	0	0	16	63	0	0	0	0	0	124	34	0	0	0	0	0
8:30 PM	0	0	14	68	0	0	0	0	0	118	30	0	0	0	0	0
8:45 PM	0	0	15	66	0	0	0	0	0	120	31	0	0	0	0	0

PM PEAK HOUR 4:00 PM to 5:00 PM	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
	0	**0**	**252**	**52**	**0**	**0**	**0**	**0**	**0**	**425**	**129**	**0**	**0**	**0**	**0**	**0**
PHF	**0.92**				**0.00**				**0.91**				**0.00**			
HV %	**0.0%**	**0.0%**	**0.4%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

8/17/2018, 6:23 PM, 236_046_TMC_Loc 4_Monday

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 4
Location: Logan Airport, MA
Street 1: Term E Arr. Entry Ramp
Street 2: Term E Arr. Entry, C-E Conn Rd
Count Date: 8/13/2018
Day of Week: Monday
Weather: Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TRUCKS

	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
Start Time	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:00 PM	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
4:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PM PEAK HOUR 4:00 PM to 5:00 PM	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
	0	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
PHF	**0.25**				**0.00**				**0.00**				**0.00**			

8/17/2018, 6:23 PM, 236_046_TMC_Loc 4_Monday

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 4
Location:	Logan Airport, MA
Street 1:	Term E Arr. Entry Ramp
Street 2:	Term E Arr. Entry, C-E Conn Rd
Count Date:	8/13/2018
Day of Week:	Monday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

PEDESTRIANS & BICYCLES

	C-E Connecting Road Northbound					Terminal E Arrival Southbound					Terminal E Arrival Entry Ramp Northeastbound					Terminal E Arrival Southeastbound				
Start Time	Hard Left	Soft Left	Thru	PED		Thru	Soft Right	Right	PED		Left	Soft Left	Hard Right	PED		Left	Thru	Right	PED	
3:00 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
3:15 PM	0	0	0	0		0	0	0	1		0	0	0	6		0	0	0	1	
3:30 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
3:45 PM	0	0	0	0		0	0	0	0		0	0	0	3		0	0	0	0	
4:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
4:15 PM	0	0	0	0		0	0	0	1		0	0	0	2		0	0	0	0	
4:30 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
4:45 PM	0	0	0	0		0	0	0	0		0	0	0	4		0	0	0	0	
5:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:15 PM	0	0	0	0		0	0	0	1		0	0	0	2		0	0	0	0	
5:30 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
5:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:00 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
6:15 PM	0	0	0	0		0	0	0	5		0	0	0	0		0	0	0	1	
6:30 PM	0	0	0	0		0	0	0	1		0	0	0	2		0	0	0	0	
6:45 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
7:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
7:15 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
7:30 PM	0	0	0	0		0	0	0	0		0	0	0	3		0	0	0	0	
7:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
8:00 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
8:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
8:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
8:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	

PM PEAK HOUR[1] 4:00 PM to 5:00 PM	C-E Connecting Road Northbound					Terminal E Arrival Southbound					Terminal E Arrival Entry Ramp Northeastbound					Terminal E Arrival Southeastbound				
	Hard Left	Soft Left	Thru	PED		Thru	Soft Right	Right	PED		Left	Soft Left	Hard Right	PED		Left	Thru	Right	PED	
	0	0	0	0		0	0	0	1		0	0	0	7		0	0	0	0	

[1] *Peak hours corresponds to vehicular peak hours.*

8/17/2018, 6:23 PM, 236_046_TMC_Loc 4_Monday

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 4
Location: Logan Airport, MA
Street 1: Term E Arr. Entry Ramp
Street 2: Term E Arr. Entry, C-E Conn Rd
Count Date: 8/12/2018
Day of Week: Sunday
Weather: Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TOTAL (CARS & TRUCKS)

	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
Start Time	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	36	33	0	0	0	0	0	122	29	0	0	0	0	0
3:15 PM	0	0	39	34	0	0	0	0	0	126	32	0	0	0	0	0
3:30 PM	0	0	42	35	0	0	0	0	0	127	34	0	0	0	0	0
3:45 PM	0	0	45	37	0	0	0	0	0	131	37	0	0	0	0	0
4:00 PM	0	0	47	36	0	0	0	0	0	133	39	0	0	0	0	0
4:15 PM	0	0	51	30	0	0	0	0	0	122	34	0	0	0	0	0
4:30 PM	0	0	53	23	0	0	0	0	0	109	28	0	0	0	0	0
4:45 PM	0	0	57	17	0	0	0	0	0	93	22	0	0	0	0	0
5:00 PM	0	0	60	11	0	0	0	0	0	75	16	0	0	0	0	0
5:15 PM	0	0	59	12	0	0	0	0	0	82	14	0	0	0	0	0
5:30 PM	0	0	57	13	0	0	0	0	0	87	11	0	0	0	0	0
5:45 PM	0	0	56	14	0	0	0	0	0	93	9	0	0	0	0	0
6:00 PM	0	0	54	12	0	0	0	0	0	98	7	0	0	0	0	0
6:15 PM	0	0	52	23	0	0	0	0	0	116	13	0	0	0	0	0
6:30 PM	0	0	48	33	0	0	0	0	0	131	18	0	0	0	0	0
6:45 PM	0	0	44	44	0	0	0	0	0	144	25	0	0	0	0	0
7:00 PM	0	0	39	54	0	0	0	0	0	155	32	0	0	0	0	0
7:15 PM	0	0	34	58	0	0	0	0	0	153	28	0	0	0	0	0
7:30 PM	0	0	28	61	0	0	0	0	0	148	23	0	0	0	0	0
7:45 PM	0	0	23	65	0	0	0	0	0	147	19	0	0	0	0	0
8:00 PM	0	0	17	68	0	0	0	0	0	143	14	0	0	0	0	0
8:15 PM	0	0	26	65	0	0	0	0	0	133	13	0	0	0	0	0
8:30 PM	0	0	35	60	0	0	0	0	0	121	12	0	0	0	0	0
8:45 PM	0	0	31	57	0	0	0	0	0	118	13	0	0	0	0	0

PM PEAK HOUR 4:00 PM to 5:00 PM	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
	0	**0**	**208**	**106**	**0**	**0**	**0**	**0**	**0**	**457**	**123**	**0**	**0**	**0**	**0**	**0**
PHF	**0.95**				**0.00**				**0.84**				**0.00**			
HV %	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

8/17/2018, 6:41 PM, 236_046_TMC_Loc 4_Sunday

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 4
Location:	Logan Airport, MA
Street 1:	Term E Arr. Entry Ramp
Street 2:	Term E Arr. Entry, C-E Conn Rd
Count Date:	8/12/2018
Day of Week:	Sunday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TRUCKS

	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
Start Time	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PM PEAK HOUR 4:00 PM to 5:00 PM	C-E Connecting Road Northbound				Terminal E Arrival Southbound				Terminal E Arrival Entry Ramp Northeastbound				Terminal E Arrival Southeastbound			
	U-Turn	Hard Left	Soft Left	Thru	U-Turn	Thru	Soft Right	Right	U-Turn	Left	Soft Left	Hard Right	U-Turn	Left	Thru	Right
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
PHF	**0.00**				**0.00**				**0.00**				**0.00**			

8/17/2018, 6:41 PM, 236_046_TMC_Loc 4_Sunday

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 4
Location:	Logan Airport, MA
Street 1:	Term E Arr. Entry Ramp
Street 2:	Term E Arr. Entry, C-E Conn Rd
Count Date:	8/12/2018
Day of Week:	Sunday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

PEDESTRIANS & BICYCLES

	C-E Connecting Road Northbound					Terminal E Arrival Southbound					Terminal E Arrival Entry Ramp Northeastbound					Terminal E Arrival Southeastbound				
Start Time	Hard Left	Soft Left	Thru	PED		Thru	Soft Right	Right	PED		Left	Soft Left	Hard Right	PED		Left	Thru	Right	PED	
3:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
3:15 PM	0	0	0	0		0	0	0	5		0	0	0	3		0	0	0	0	
3:30 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
3:45 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
4:00 PM	0	0	0	0		0	0	0	1		0	0	0	2		0	0	0	0	
4:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
4:30 PM	0	0	0	0		0	0	0	0		0	0	0	9		0	0	0	1	
4:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:00 PM	0	0	0	0		0	0	0	1		0	0	0	1		0	0	0	0	
5:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
5:30 PM	0	0	0	0		0	0	0	1		0	0	0	1		0	0	0	0	
5:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:00 PM	0	0	0	0		0	0	0	1		0	0	0	0		0	0	0	0	
6:15 PM	0	0	0	0		0	0	0	3		0	0	0	1		0	0	0	0	
6:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
6:45 PM	0	0	0	0		0	0	0	1		0	0	0	3		0	0	0	0	
7:00 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
7:15 PM	0	0	0	0		0	0	0	1		0	0	0	6		0	0	0	1	
7:30 PM	0	0	0	0		0	0	0	0		0	0	0	2		0	0	0	0	
7:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
8:00 PM	0	0	0	0		0	0	0	0		0	0	0	1		0	0	0	0	
8:15 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
8:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
8:45 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	

PM PEAK HOUR[1]	C-E Connecting Road Northbound					Terminal E Arrival Southbound					Terminal E Arrival Entry Ramp Northeastbound					Terminal E Arrival Southeastbound				
4:00 PM to	Hard Left	Soft Left	Thru	PED		Thru	Soft Right	Right	PED		Left	Soft Left	Hard Right	PED		Left	Thru	Right	PED	
5:00 PM	0	0	0	0		0	0	0	1		0	0	0	11		0	0	0	1	

[1] *Peak hours corresponds to vehicular peak hours.*

8/17/2018, 6:41 PM, 236_046_TMC_Loc 4_Sunday

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 5
Location:	Logan Airport, MA
Street 1:	Terminal E Arrival Exit
Street 2:	Service Road
Count Date:	8/14/2018
Day of Week:	Tuesday
Weather:	Mostly Cloudy w/ Showers, 80°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TOTAL (CARS & TRUCKS)

	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	0	0	0	127	24	0	0	0	0	31	0	0	0	0
3:15 PM	0	0	0	0	0	132	26	0	0	0	0	34	0	0	0	0
3:30 PM	0	0	0	0	0	149	29	0	0	0	0	32	0	0	0	0
3:45 PM	0	0	0	0	0	163	31	0	0	0	0	30	0	0	0	0
4:00 PM	0	0	0	0	0	182	34	0	0	0	0	28	0	0	0	0
4:15 PM	0	0	0	0	0	198	37	0	0	0	0	25	0	0	0	0
4:30 PM	0	0	0	0	0	180	35	0	0	0	0	24	0	0	0	0
4:45 PM	0	0	0	0	0	159	32	0	0	0	0	22	0	0	0	0
5:00 PM	0	0	0	0	0	141	30	0	0	0	0	21	0	0	0	0
5:15 PM	0	0	0	0	0	120	28	0	0	0	0	19	0	0	0	0
5:30 PM	0	0	0	0	0	124	29	0	0	0	0	21	0	0	0	0
5:45 PM	0	0	0	0	0	122	30	0	0	0	0	23	0	0	0	0
6:00 PM	0	0	0	0	0	125	31	0	0	0	0	26	0	0	0	0
6:15 PM	0	0	0	0	0	126	29	0	0	0	0	28	0	0	0	0
6:30 PM	0	0	0	0	0	141	30	0	0	0	0	29	0	0	0	0
6:45 PM	0	0	0	0	0	154	31	0	0	0	0	30	0	0	0	0
7:00 PM	0	0	0	0	0	172	33	0	0	0	0	32	0	0	0	0
7:15 PM	0	0	0	0	0	187	32	0	0	0	0	33	0	0	0	0
7:30 PM	0	0	0	0	0	183	34	0	0	0	0	32	0	0	0	0
7:45 PM	0	0	0	0	0	175	30	0	0	0	0	30	0	0	0	0
8:00 PM	0	0	0	0	0	170	31	0	0	0	0	29	0	0	0	0
8:15 PM	0	0	0	0	0	162	32	0	0	0	0	28	0	0	0	0
8:30 PM	0	0	0	0	0	165	30	0	0	0	0	29	0	0	0	0
8:45 PM	0	0	0	0	0	159	31	0	0	0	0	27	0	0	0	0

PM PEAK HOUR 4:00 PM to 5:00 PM	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
	0	**0**	**0**	**0**	**0**	**719**	**138**	**0**	**0**	**0**	**0**	**99**	**0**	**0**	**0**	**0**
PHF	**0.00**				**0.91**				**0.88**				**0.00**			
HV %	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**1.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

8/17/2018, 6:45 PM, 236_046_TMC_Loc 5 Tuesday

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 5
Location:	Logan Airport, MA
Street 1:	Terminal E Arrival Exit
Street 2:	Service Road
Count Date:	8/14/2018
Day of Week:	Tuesday
Weather:	Mostly Cloudy w/ Showers, 80°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TRUCKS

	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:15 PM	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
4:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PM PEAK HOUR	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
4:00 PM to	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
5:00 PM	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
PHF	**0.00**				**0.00**				**0.25**				**0.00**			

8/17/2018, 6:45 PM, 236_046_TMC_Loc 5 Tuesday

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 5
Location: Logan Airport, MA
Street 1: Terminal E Arrival Exit
Street 2: Service Road
Count Date: 8/14/2018
Day of Week: Tuesday
Weather: Mostly Cloudy w/ Showers, 80°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

PEDESTRIANS & BICYCLES

	Terminal E Arrival Northbound					Terminal E Arrival Exit Southbound					Service Road Eastbound					Westbound				
Start Time	Left	Thru	Right	PED		Soft Left	Thru	Right	PED		Left	Thru	Soft Right	PED		Left	Thru	Right	PED	
3:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
3:15 PM	0	0	0	2		0	0	0	0		0	0	0	0		0	0	0	0	
3:30 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
3:45 PM	0	0	0	1		0	0	0	1		0	0	0	1		0	0	0	0	
4:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
4:15 PM	0	0	0	2		0	0	0	0		0	0	0	0		0	0	0	0	
4:30 PM	0	0	0	4		0	0	0	0		0	0	0	0		0	0	0	0	
4:45 PM	0	0	0	2		0	0	0	0		0	0	0	0		0	0	0	0	
5:00 PM	0	0	0	2		0	0	0	0		0	0	0	0		0	0	0	0	
5:15 PM	0	0	0	3		0	0	0	1		0	0	0	1		0	0	0	0	
5:30 PM	0	0	0	1		0	0	0	0		0	0	0	0		0	0	0	0	
5:45 PM	0	0	0	3		0	0	0	0		0	0	0	0		0	0	0	0	
6:00 PM	0	0	0	2		0	0	0	0		0	0	0	0		0	0	0	0	
6:15 PM	0	0	0	4		0	0	0	3		0	0	0	3		0	0	0	0	
6:30 PM	0	0	0	8		0	0	0	0		0	0	0	0		0	0	0	0	
6:45 PM	0	0	0	11		0	0	0	0		0	0	0	0		0	0	0	0	
7:00 PM	0	0	0	10		0	0	0	0		0	0	0	0		0	0	0	0	
7:15 PM	0	0	0	12		0	0	0	1		0	0	0	1		0	0	0	0	
7:30 PM	0	0	0	8		0	0	0	2		0	0	0	0		0	0	0	0	
7:45 PM	0	0	0	14		0	0	0	1		0	0	0	1		0	0	0	0	
8:00 PM	0	0	0	5		0	0	0	0		0	0	0	0		0	0	0	0	
8:15 PM	0	0	0	18		0	0	0	0		0	0	0	0		0	0	0	0	
8:30 PM	0	0	0	14		0	0	0	0		0	0	0	0		0	0	0	0	
8:45 PM	0	0	0	12		0	0	0	0		0	0	0	0		0	0	0	0	

PM PEAK HOUR[1] 4:00 PM to 5:00 PM	Terminal E Arrival Northbound					Terminal E Arrival Exit Southbound					Service Road Eastbound					Westbound				
	Left	Thru	Right	PED		Soft Left	Thru	Right	PED		Left	Thru	Soft Right	PED		Left	Thru	Right	PED	
	0	0	0	8		0	0	0	0		0	0	0	0		0	0	0	0	

[1] *Peak hours corresponds to vehicular peak hours.*

8/17/2018, 6:45 PM, 236_046_TMC_Loc 5 Tuesday

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 5
Location:	Logan Airport, MA
Street 1:	Terminal E Arrival Exit
Street 2:	Service Road
Count Date:	8/13/2018
Day of Week:	Monday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TOTAL (CARS & TRUCKS)

	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	0	0	0	174	34	0	0	0	0	42	0	0	0	0
3:15 PM	0	0	0	0	0	179	36	0	0	0	0	45	0	0	0	0
3:30 PM	0	0	0	0	0	183	37	0	0	0	0	44	0	0	0	0
3:45 PM	0	0	0	0	0	184	38	0	0	0	0	42	0	0	0	0
4:00 PM	0	0	0	0	0	186	40	0	0	0	0	41	0	0	0	0
4:15 PM	0	0	0	0	0	188	41	0	0	0	0	40	0	0	0	0
4:30 PM	0	0	0	0	0	185	38	0	0	0	0	37	0	0	0	0
4:45 PM	0	0	0	0	0	179	35	0	0	0	0	33	0	0	0	0
5:00 PM	0	0	0	0	0	176	32	0	0	0	0	29	0	0	0	0
5:15 PM	0	0	0	0	0	170	28	0	0	0	0	25	0	0	0	0
5:30 PM	0	0	0	0	0	167	29	0	0	0	0	28	0	0	0	0
5:45 PM	0	0	0	0	0	161	30	0	0	0	0	31	0	0	0	0
6:00 PM	0	0	0	0	0	158	32	0	0	0	0	35	0	0	0	0
6:15 PM	0	0	0	0	0	152	33	0	0	0	0	38	0	0	0	0
6:30 PM	0	0	0	0	0	159	36	0	0	0	0	39	0	0	0	0
6:45 PM	0	0	0	0	0	163	38	0	0	0	0	40	0	0	0	0
7:00 PM	0	0	0	0	0	165	41	0	0	0	0	42	0	0	0	0
7:15 PM	0	0	0	0	0	164	44	0	0	0	0	43	0	0	0	0
7:30 PM	0	0	0	0	0	168	42	0	0	0	0	42	0	0	0	0
7:45 PM	0	0	0	0	0	169	45	0	0	0	0	40	0	0	0	0
8:00 PM	0	0	0	0	0	172	43	0	0	0	0	39	0	0	0	0
8:15 PM	0	0	0	0	0	175	46	0	0	0	0	37	0	0	0	0
8:30 PM	0	0	0	0	0	173	45	0	0	0	0	38	0	0	0	0
8:45 PM	0	0	0	0	0	170	44	0	0	0	0	36	0	0	0	0

PM PEAK HOUR 4:00 PM to 5:00 PM	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
	0	**0**	**0**	**0**	**0**	**738**	**154**	**0**	**0**	**0**	**0**	**151**	**0**	**0**	**0**	**0**
PHF	**0.00**				**0.97**				**0.92**				**0.00**			
HV %	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

8/17/2018, 6:48 PM, 236_046_TMC_Loc 5_Monday

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 5
Location:	Logan Airport, MA
Street 1:	Terminal E Arrival Exit
Street 2:	Service Road
Count Date:	8/13/2018
Day of Week:	Monday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TRUCKS

	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:15 PM	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
3:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:45 PM	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
6:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:15 PM	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
6:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PM PEAK HOUR 5:00 PM to 6:00 PM	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
	0	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
PHF	**0.00**				**0.25**				**0.00**				**0.00**			

8/17/2018, 6:48 PM, 236_046_TMC_Loc 5_Monday

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 5
Location:	Logan Airport, MA
Street 1:	Terminal E Arrival Exit
Street 2:	Service Road
Count Date:	8/13/2018
Day of Week:	Monday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

PEDESTRIANS & BICYCLES

	Terminal E Arrival Northbound					Terminal E Arrival Exit Southbound					Service Road Eastbound					Westbound				
Start Time	Left	Thru	Right	PED		Soft Left	Thru	Right	PED		Left	Thru	Soft Right	PED		Left	Thru	Right	PED	
3:00 PM	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
3:15 PM	0	0	0	1		0	0	0	0		0	0	0	0		0	0	0	0	
3:30 PM	0	0	0	4		0	0	0	1		0	0	0	1		0	0	0	0	
3:45 PM	0	0	0	1		0	0	0	0		0	0	0	0		0	0	0	0	
4:00 PM	0	0	0	7		0	0	0	2		0	0	0	2		0	0	0	0	
4:15 PM	0	0	0	13		0	0	0	0		0	0	0	0		0	0	0	0	
4:30 PM	0	0	0	3		0	0	0	0		0	0	0	0		0	0	0	0	
4:45 PM	0	0	0	4		0	0	0	1		0	0	0	1		0	0	0	0	
5:00 PM	0	0	0	2		0	0	0	0		0	0	0	0		0	0	0	0	
5:15 PM	0	0	0	8		0	0	0	7		0	0	0	7		0	0	0	0	
5:30 PM	0	0	0	5		0	0	0	0		0	0	0	0		0	0	0	0	
5:45 PM	0	0	0	6		0	0	0	3		0	0	0	3		0	0	0	0	
6:00 PM	0	0	0	4		0	0	0	4		0	0	0	4		0	0	0	0	
6:15 PM	0	0	0	7		0	0	0	1		0	0	0	1		0	0	0	0	
6:30 PM	0	0	0	2		0	0	0	3		0	0	0	3		0	0	0	0	
6:45 PM	0	0	0	3		0	0	0	0		0	0	0	0		0	0	0	0	
7:00 PM	0	0	0	4		0	0	0	0		0	0	0	0		0	0	0	0	
7:15 PM	0	0	0	8		0	0	0	3		0	0	0	3		0	0	0	0	
7:30 PM	0	0	0	5		0	0	0	1		0	0	0	1		0	0	0	0	
7:45 PM	0	0	0	3		0	0	0	0		0	0	0	0		0	0	0	0	
8:00 PM	0	0	0	6		0	0	0	0		0	0	0	0		0	0	0	0	
8:15 PM	0	0	0	11		0	0	0	3		0	0	0	3		0	0	0	0	
8:30 PM	0	0	0	12		0	0	0	0		0	0	0	0		0	0	0	0	
8:45 PM	0	0	0	10		0	0	0	0		0	0	0	0		0	0	0	0	

PM PEAK HOUR[1] 4:00 PM to 5:00 PM	Terminal E Arrival Northbound					Terminal E Arrival Exit Southbound					Service Road Eastbound					Westbound				
	Left	Thru	Right	PED		Soft Left	Thru	Right	PED		Left	Thru	Soft Right	PED		Left	Thru	Right	PED	
	0	0	0	27		0	0	0	3		0	0	0	3		0	0	0	0	

[1] *Peak hours corresponds to vehicular peak hours.*

8/17/2018, 6:48 PM, 236_046_TMC_Loc 5_Monday

Client:	Ashley Berthaume
Project #:	236_046_VHB
BTD #:	Location 5
Location:	Logan Airport, MA
Street 1:	Terminal E Arrival Exit
Street 2:	Service Road
Count Date:	8/12/2018
Day of Week:	Sunday
Weather:	Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TOTAL (CARS & TRUCKS)

	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	0	0	0	184	36	0	0	0	0	35	0	0	0	0
3:15 PM	0	0	0	0	0	187	39	0	0	0	0	38	0	0	0	0
3:30 PM	0	0	0	0	0	196	38	0	0	0	0	36	0	0	0	0
3:45 PM	0	0	0	0	0	202	37	0	0	0	0	33	0	0	0	0
4:00 PM	0	0	0	0	0	210	36	0	0	0	0	30	0	0	0	0
4:15 PM	0	0	0	0	0	213	35	0	0	0	0	27	0	0	0	0
4:30 PM	0	0	0	0	0	208	36	0	0	0	0	28	0	0	0	0
4:45 PM	0	0	0	0	0	198	34	0	0	0	0	29	0	0	0	0
5:00 PM	0	0	0	0	0	191	35	0	0	0	0	29	0	0	0	0
5:15 PM	0	0	0	0	0	181	36	0	0	0	0	28	0	0	0	0
5:30 PM	0	0	0	0	0	179	38	0	0	0	0	31	0	0	0	0
5:45 PM	0	0	0	0	0	173	35	0	0	0	0	34	0	0	0	0
6:00 PM	0	0	0	0	0	170	36	0	0	0	0	36	0	0	0	0
6:15 PM	0	0	0	0	0	164	37	0	0	0	0	38	0	0	0	0
6:30 PM	0	0	0	0	0	189	43	0	0	0	0	34	0	0	0	0
6:45 PM	0	0	0	0	0	211	49	0	0	0	0	29	0	0	0	0
7:00 PM	0	0	0	0	0	213	48	0	0	0	0	38	0	0	0	0
7:15 PM	0	0	0	0	0	215	47	0	0	0	0	46	0	0	0	0
7:30 PM	0	0	0	0	0	218	46	0	0	0	0	45	0	0	0	0
7:45 PM	0	0	0	0	0	220	44	0	0	0	0	47	0	0	0	0
8:00 PM	0	0	0	0	0	226	43	0	0	0	0	48	0	0	0	0
8:15 PM	0	0	0	0	0	227	41	0	0	0	0	49	0	0	0	0
8:30 PM	0	0	0	0	0	225	42	0	0	0	0	48	0	0	0	0
8:45 PM	0	0	0	0	0	223	40	0	0	0	0	46	0	0	0	0

PM PEAK HOUR 4:00 PM to 5:00 PM	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
	0	**0**	**0**	**0**	**0**	**829**	**141**	**0**	**0**	**0**	**0**	**114**	**0**	**0**	**0**	**0**
PHF	**0.00**				**0.98**				**0.95**				**0.00**			
HV %	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

8/17/2018, 7:08 PM, 236_046_TMC_Loc 5_Sunday

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 5
Location: Logan Airport, MA
Street 1: Terminal E Arrival Exit
Street 2: Service Road
Count Date: 8/12/2018
Day of Week: Sunday
Weather: Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

TRUCKS

	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
Start Time	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
3:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:00 PM	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
5:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PM PEAK HOUR 4:15 PM to 5:15 PM	Terminal E Arrival Northbound				Terminal E Arrival Exit Southbound				Service Road Eastbound				Westbound			
	U-Turn	Left	Thru	Right	U-Turn	Soft Left	Thru	Right	U-Turn	Left	Thru	Soft Right	U-Turn	Left	Thru	Right
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
PHF	**0.00**				**0.00**				**0.25**				**0.00**			

8/17/2018, 7:08 PM, 236_046_TMC_Loc 5_Sunday

Client: Ashley Berthaume
Project #: 236_046_VHB
BTD #: Location 5
Location: Logan Airport, MA
Street 1: Terminal E Arrival Exit
Street 2: Service Road
Count Date: 8/12/2018
Day of Week: Sunday
Weather: Mostly Cloudy w/ Showers, 75°F

BOSTON TRAFFIC DATA
PO BOX 1723, Framingham, MA 01701
Office: 978-746-1259
DataRequest@BostonTrafficData.com
www.BostonTrafficData.com

PEDESTRIANS & BICYCLES

	Terminal E Arrival Northbound					Terminal E Arrival Exit Southbound					Service Road Eastbound					Westbound				
Start Time	Left	Thru	Right	PED		Soft Left	Thru	Right	PED		Left	Thru	Soft Right	PED		Left	Thru	Right	PED	
3:00 PM	0	0	0	1		0	0	0	4		0	0	0	4		0	0	0	0	
3:15 PM	0	0	0	1		0	0	0	0		0	0	0	0		0	0	0	0	
3:30 PM	0	0	0	6		0	0	0	1		0	0	0	1		0	0	0	0	
3:45 PM	0	0	0	9		0	0	0	0		0	0	0	0		0	0	0	0	
4:00 PM	0	0	0	1		0	0	0	3		0	0	0	3		0	0	0	0	
4:15 PM	0	0	0	6		0	0	0	2		0	0	0	2		0	0	0	0	
4:30 PM	0	0	0	3		0	0	0	2		0	0	0	2		0	0	0	0	
4:45 PM	0	0	0	2		0	0	0	1		0	0	0	1		0	0	0	0	
5:00 PM	0	0	0	6		0	0	0	0		0	0	0	0		0	0	0	0	
5:15 PM	0	0	0	18		0	0	0	2		0	0	0	2		0	0	0	0	
5:30 PM	0	0	0	3		0	0	0	0		0	0	0	0		0	0	0	0	
5:45 PM	0	0	0	2		0	0	0	0		0	0	0	0		0	0	0	0	
6:00 PM	0	0	0	8		0	0	0	2		0	0	0	2		0	0	0	0	
6:15 PM	0	0	0	10		0	0	0	0		0	0	0	0		0	0	0	0	
6:30 PM	0	0	0	2		0	0	0	1		0	0	0	1		0	0	0	0	
6:45 PM	0	0	0	7		0	0	0	1		0	0	0	1		0	0	0	0	
7:00 PM	0	0	0	11		0	0	0	2		0	0	0	2		0	0	0	0	
7:15 PM	0	0	0	28		0	0	0	1		0	0	0	1		0	0	0	0	
7:30 PM	0	0	0	26		0	0	0	2		0	0	0	2		0	0	0	0	
7:45 PM	0	0	0	24		0	0	0	3		0	0	0	3		0	0	0	0	
8:00 PM	0	0	0	37		0	0	0	1		0	0	0	1		0	0	0	0	
8:15 PM	0	0	0	29		0	0	0	2		0	0	0	2		0	0	0	0	
8:30 PM	0	0	0	32		0	0	0	2		0	0	0	2		0	0	0	0	
8:45 PM	0	0	0	28		0	0	0	1		0	0	0	1		0	0	0	0	

PM PEAK HOUR[1]	Terminal E Arrival Northbound					Terminal E Arrival Exit Southbound					Service Road Eastbound					Westbound				
4:00 PM to	Left	Thru	Right	PED		Soft Left	Thru	Right	PED		Left	Thru	Soft Right	PED		Left	Thru	Right	PED	
5:00 PM	0	0	0	12		0	0	0	8		0	0	0	8		0	0	0	0	

[1] *Peak hours corresponds to vehicular peak hours.*

8/17/2018, 7:08 PM, 236_046_TMC_Loc 5_Sunday

Basic Axle Classification Report: 236_046_VHB_ATR 1

Station ID : 236_046_VHB_ATR 1
Info Line 1 : Term E Departure Entry Ramp
Info Line 2 : Logan Airport
GPS Lat/Lon :
DB File : 236046VHBATR 1.DB

Last Connected Device Type : RoadRunner3
Version Number : 1.32
Serial Number : 17749
Number of Lanes : 1
Posted Speed Limit : 0.0 mph

Lane #1 Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length	Comment
1.	N	North	Ax-Ax	3.0 ft	6.0 ft	

Lane #1 Basic Axle Classification Data From: 22:00 - 08/10/2018 To: 02:59 - 08/15/2018

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/10/18	22:00	1	1	0	0	0	1	0	0	0	0	0	0	0	3
Fri	23:00	0	46	5	0	2	0	0	8	0	0	0	0	0	61
Daily Total :		1	47	5	0	2	1	0	8	0	0	0	0	0	64
Percent :		2%	73%	8%	0%	3%	2%	0%	13%	0%	0%	0%	0%	0%	
Average :		1	24	3	0	1	1	0	4	0	0	0	0	0	34

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/11/18	00:00	0	32	2	0	2	0	0	8	0	0	0	0	0	44
Sat	01:00	1	13	2	0	0	0	0	7	0	0	0	0	0	23
	02:00	1	6	0	0	0	0	0	8	0	0	0	0	0	15
	03:00	2	20	0	0	1	0	0	12	0	0	0	0	0	35
	04:00	2	31	9	0	0	0	0	10	0	0	0	0	0	52
	05:00	3	80	8	0	0	0	0	16	0	0	0	0	0	107
	06:00	3	102	7	0	1	0	1	10	0	0	0	0	0	124
	07:00	4	89	18	0	0	0	1	17	0	0	0	0	1	130
	08:00	5	46	6	0	3	0	0	13	0	0	0	0	0	73
	09:00	7	54	12	0	2	0	0	16	0	0	0	0	0	91
	10:00	7	86	12	0	1	0	0	14	0	3	0	0	0	123
	11:00	8	78	7	0	3	0	0	15	0	0	0	1	1	113
	12:00	7	119	11	0	2	0	1	19	0	1	0	0	1	161
	13:00	6	188	15	0	2	0	1	20	0	1	1	1	0	235
	14:00	7	292	25	0	1	0	0	20	0	1	0	2	2	350
	15:00	7	247	28	0	2	0	0	23	0	1	4	1	1	314
	16:00	9	228	23	0	3	0	0	26	0	2	1	2	2	296
	17:00	10	277	20	1	2	0	0	27	0	0	0	0	4	341
	18:00	5	263	35	2	3	0	0	20	1	7	7	2	10	355
	19:00	6	337	29	0	2	0	0	19	0	4	1	4	4	406
	20:00	7	302	17	0	5	0	0	15	0	2	0	5	3	356
	21:00	5	142	10	0	5	0	0	17	0	2	0	3	0	184
	22:00	2	81	6	0	0	0	0	15	0	0	1	0	0	105
	23:00	0	71	6	0	0	0	1	14	0	0	0	0	0	92
Daily Total :		114	3184	308	3	40	0	5	381	1	24	15	21	29	4125
Percent :		3%	77%	7%	0%	1%	0%	0%	9%	0%	1%	0%	1%	1%	
Average :		5	133	13	0	2	0	0	16	0	1	1	1	1	173

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/12/18	00:00	0	30	3	0	1	0	0	9	0	0	0	0	0	43
Sun	01:00	2	8	1	0	1	0	0	3	0	0	0	0	0	15
	02:00	5	4	1	0	0	0	0	8	0	0	0	0	0	18
	03:00	4	13	4	0	0	0	0	8	0	0	0	0	0	29
	04:00	4	44	5	0	1	0	0	9	0	0	0	0	0	63
	05:00	3	86	5	0	1	0	0	10	0	0	0	0	0	105
	06:00	4	62	2	0	1	0	0	8	0	0	0	0	0	77
	07:00	0	70	12	0	0	0	0	21	0	0	0	0	0	103
	08:00	2	45	7	0	0	0	0	21	0	0	0	0	0	75
	09:00	4	56	6	0	1	0	0	17	0	0	0	0	1	85
	10:00	8	72	8	0	1	0	0	13	0	1	0	1	0	104
	11:00	11	96	12	0	0	0	0	15	0	0	0	0	1	135
	12:00	9	110	17	0	2	0	0	16	0	0	0	0	0	154
	13:00	6	210	22	0	2	0	0	18	0	1	0	0	0	259
	14:00	10	264	23	0	2	0	1	23	0	5	0	6	3	337
	15:00	10	253	28	0	5	0	2	19	0	0	3	6	1	327
	16:00	8	240	25	1	0	1	1	17	0	1	0	1	1	296
	17:00	12	261	16	0	2	0	0	14	0	7	0	5	17	334
	18:00	9	203	30	5	1	3	0	18	0	10	7	10	25	321
	19:00	3	136	13	9	2	1	1	6	0	6	7	8	29	221
	20:00	8	266	22	2	7	0	0	12	0	0	3	9	16	345
	21:00	7	149	10	0	7	1	0	11	0	0	0	0	0	185
	22:00	6	78	6	0	0	0	1	9	0	0	0	0	0	100
	23:00	2	57	5	0	0	0	1	14	0	0	0	1	0	80
Daily Total :		137	2813	283	17	37	6	7	319	0	31	20	47	94	3811
Percent :		4%	74%	7%	0%	1%	0%	0%	8%	0%	1%	1%	1%	2%	
Average :		6	117	12	1	2	0	0	13	0	1	1	2	4	159

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/13/18	00:00	0	30	3	0	1	0	0	7	0	0	0	0	0	41
Mon	01:00	0	5	0	0	0	0	0	8	0	0	0	0	0	13
	02:00	0	3	0	0	0	0	0	11	0	0	0	0	0	14
	03:00	1	15	5	0	0	0	0	12	0	0	0	0	0	33
	04:00	2	46	9	0	0	0	0	10	0	0	0	0	0	67
	05:00	2	108	6	0	0	0	0	14	0	0	0	1	0	131
	06:00	3	83	12	0	2	0	0	10	0	1	0	0	0	111
	07:00	7	75	10	0	2	0	0	12	0	0	0	0	0	106
	08:00	8	47	9	0	1	0	0	13	0	0	0	0	0	78
	09:00	7	55	12	0	1	0	0	17	0	0	0	0	1	93
	10:00	10	84	8	0	0	0	0	16	0	0	0	0	0	118
	11:00	10	89	13	0	2	0	1	14	0	0	0	0	0	129
	12:00	7	113	14	0	1	0	0	22	0	0	2	0	0	159
	13:00	9	169	18	0	3	0	0	18	0	0	1	0	0	218
	14:00	9	291	24	0	1	0	0	25	0	2	0	3	2	357
	15:00	7	286	34	0	5	0	1	24	0	3	0	3	6	369
	16:00	8	277	27	0	2	0	2	27	1	3	0	6	4	357
	17:00	9	278	26	0	2	1	0	20	0	5	0	3	3	347
	18:00	6	261	17	2	1	0	1	21	0	3	2	1	9	324
	19:00	6	269	15	2	2	1	0	14	0	10	2	7	19	347
	20:00	2	40	6	0	0	0	0	2	0	0	0	1	3	54
	21:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	22:00	1	8	0	0	0	0	0	0	0	0	0	0	0	9
	23:00	0	55	11	0	0	0	0	10	0	0	0	0	0	76
Daily Total :		114	2687	279	4	26	2	5	327	1	27	7	25	47	3551
Percent :		3%	76%	8%	0%	1%	0%	0%	9%	0%	1%	0%	1%	1%	
Average :		5	112	12	0	1	0	0	14	0	1	0	1	2	148

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/14/18	00:00	0	23	2	0	1	0	0	9	0	0	0	0	0	35
Tue	01:00	0	14	0	0	0	0	0	8	0	0	0	0	0	22
	02:00	2	8	1	0	0	0	0	8	0	0	0	0	0	19
	03:00	2	13	3	0	0	0	0	10	0	0	0	0	0	28
	04:00	2	34	6	0	0	0	0	10	0	0	0	0	0	52
	05:00	2	92	12	0	1	0	0	13	0	0	1	0	0	121
	06:00	3	62	7	0	1	1	0	5	0	1	0	0	0	80
	07:00	5	65	11	0	2	0	0	16	0	1	0	0	0	100
	08:00	5	26	14	0	1	1	0	19	0	0	1	0	0	67
	09:00	6	53	6	0	0	1	0	20	0	1	1	0	0	88
	10:00	7	81	9	0	2	1	1	21	0	0	1	0	0	123
	11:00	6	84	10	0	3	0	0	23	0	1	0	1	0	128
	12:00	3	94	16	0	2	0	0	22	0	0	0	0	0	137
	13:00	8	167	14	0	1	0	1	22	0	1	0	0	1	215
	14:00	5	243	15	0	0	0	0	21	0	1	2	3	0	290
	15:00	7	200	15	0	5	0	0	28	0	3	2	2	0	262
	16:00	9	234	16	0	2	0	0	26	0	1	0	2	1	291
	17:00	7	254	26	1	3	0	0	27	0	1	0	4	2	325
	18:00	10	289	22	0	2	0	1	24	1	5	1	3	8	366
	19:00	5	328	29	0	1	0	0	17	0	4	2	6	11	403
	20:00	6	222	18	0	6	0	0	16	0	0	1	2	1	272
	21:00	4	149	7	0	3	0	0	17	0	1	0	0	0	181
	22:00	1	73	8	0	1	0	0	10	0	0	0	0	0	93
	23:00	0	69	13	0	0	0	0	14	0	0	0	0	0	96
Daily Total :		105	2877	280	1	37	4	3	406	1	21	12	23	24	3794
Percent :		3%	76%	7%	0%	1%	0%	0%	11%	0%	1%	0%	1%	1%	
Average :		4	120	12	0	2	0	0	17	0	1	1	1	1	159

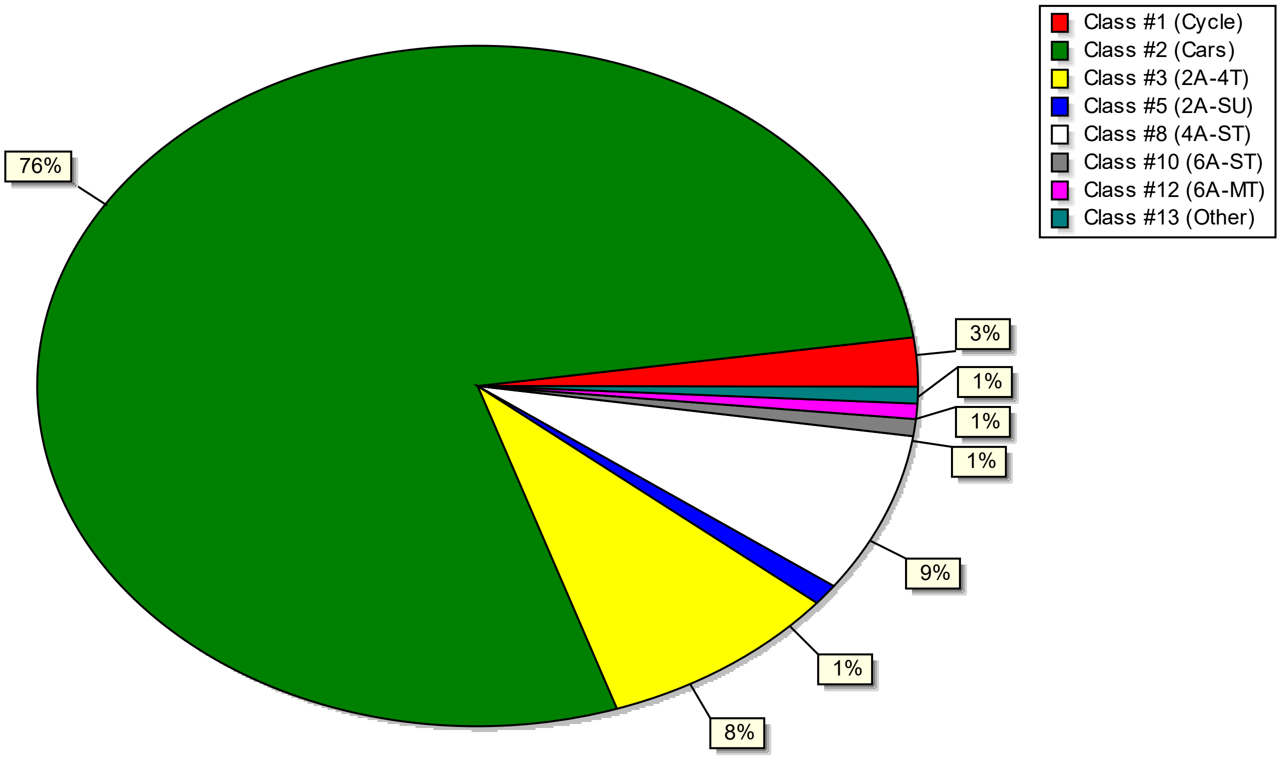
(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/15/18	00:00	0	30	2	0	1	0	0	8	0	0	0	0	0	41
Wed	01:00	0	15	2	0	0	0	0	6	0	0	0	0	0	23
	02:00	2	7	0	0	1	0	0	7	0	0	0	0	0	17
Daily Total :		2	52	4	0	2	0	0	21	0	0	0	0	0	81
Percent :		2%	64%	5%	0%	2%	0%	0%	26%	0%	0%	0%	0%	0%	
Average :		1	17	1	0	1	0	0	7	0	0	0	0	0	27

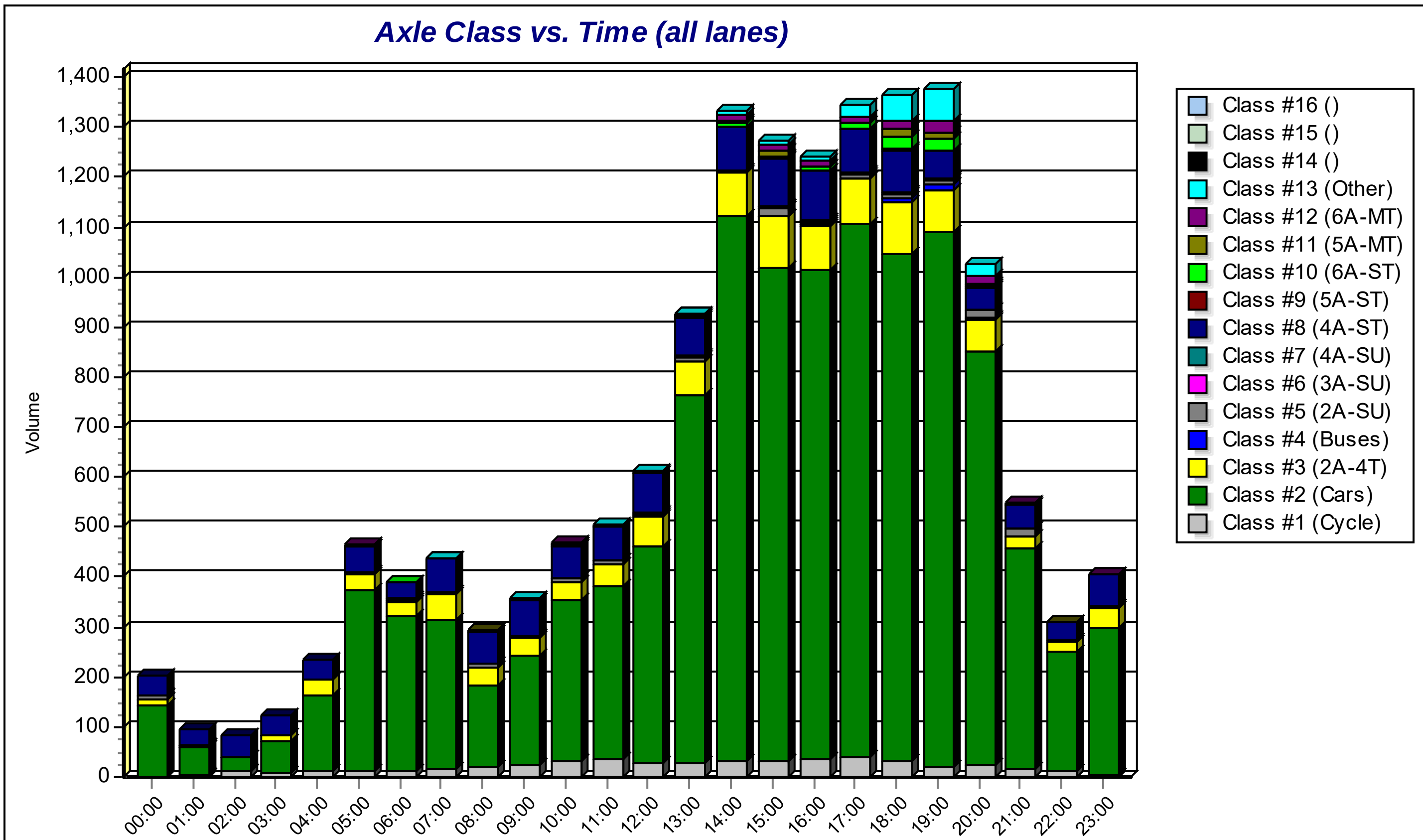
Basic Axle Class Summary: 236_046_VHB_ATR 1

(DEFAULTC) Description	Lane	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
TOTAL COUNT :	#1.	473	11660	1159	25	144	13	20	1462	3	103	54	116	194	15426
		473	11660	1159	25	144	13	20	1462	3	103	54	116	194	15426
Percents :	#1.	3%	76%	8%	0%	1%	0%	0%	9%	0%	1%	0%	1%	1%	100%
		3%	76%	8%	0%	1%	0%	0%	9%	0%	1%	0%	1%	1%	
Average :	#1.	5	115	11	0	1	0	0	14	0	1	1	1	2	151
		5	115	11	0	1	0	0	14	0	1	1	1	2	151
Days & ADT :	#1.	4.2	3665												
		4.2	3665												

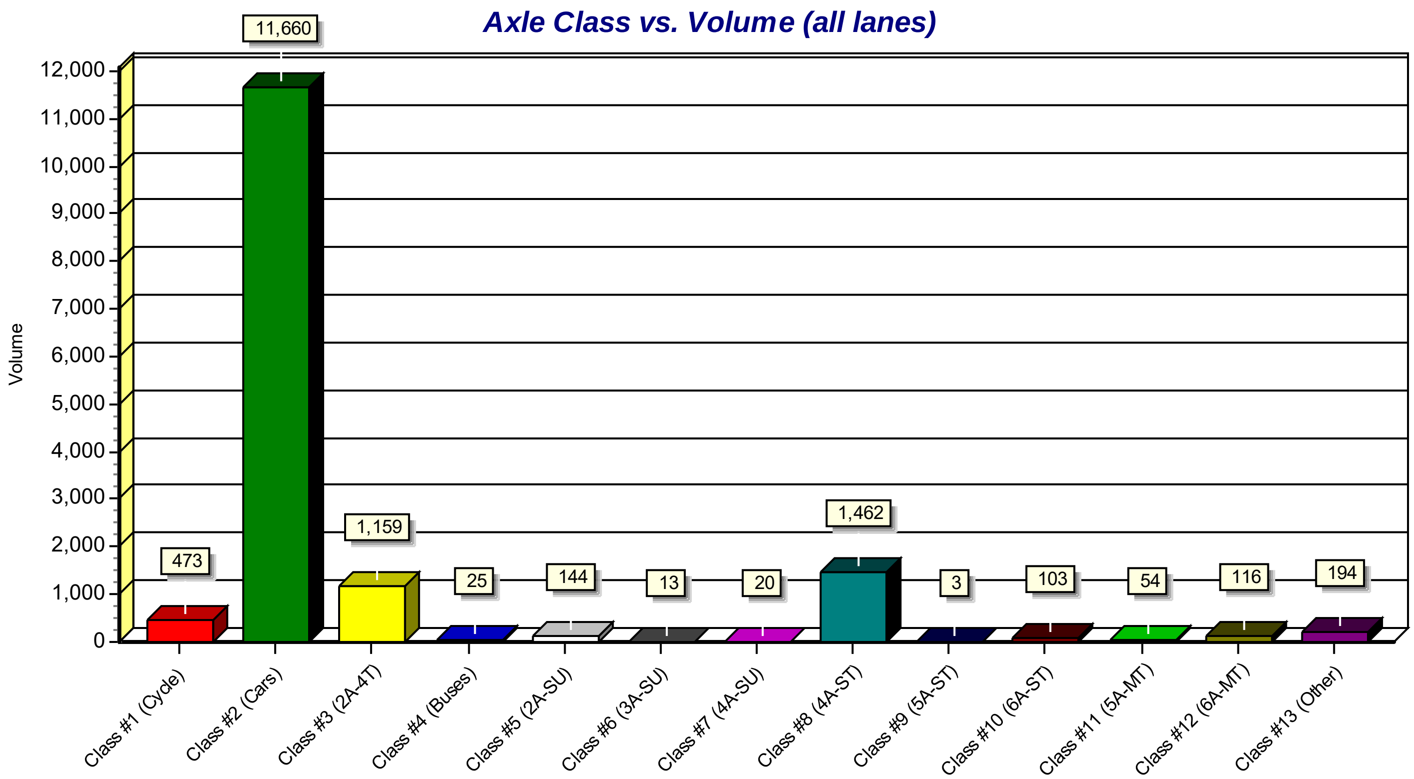
236_046_VHB_ATR 1 Axle Class Charts For Data From: 22:00 - 08/10/2018 To: 02:59 - 08/15/2018

Axle Class Percentages:





236_046_VHB_ATR 1 Axle Class Charts For Data From: 22:00 - 08/10/2018 To: 02:59 - 08/15/2018



Basic Speed Classification Report: 236_046_VHB_ATR

Lane #1 Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length	Comment
1.	N	North	Ax-Ax	3.0 ft	6.0 ft	

Lane #1 Basic Speed Classification Data From: 22:00 - 08/10/2018 To: 02:59 - 08/15/2018

(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
Date	Time	0.0 - 19.9	20.0 - 24.9	25.0 - 29.9	30.0 - 34.9	35.0 - 39.9	40.0 - 44.9	45.0 - 49.9	50.0 - 54.9	55.0 - 59.9	60.0 - 64.9	65.0 - 69.9	70.0 - 74.9	75.0 - 79.9	80.0 - 84.9	85.0 - 89.9	Other	Total
08/10/18	22:00	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	3
Fri	23:00	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	61
Daily Total :		61	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	64
Percent :		95%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	
Average :		31	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	151

Speeds - Average: 9.9 50% : 10.1 67% : 10.7 85% : 11.5 10mph Pace: 8.1 - 18.0 (95.3%)

(DEFAULTX) Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
08/11/18	00:00	42	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44
Sat	01:00	19	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23
	02:00	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
	03:00	33	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35
	04:00	51	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52
	05:00	105	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	107
	06:00	120	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	124
	07:00	128	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	130
	08:00	68	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73
	09:00	90	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	91
	10:00	120	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	123
	11:00	112	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113
	12:00	159	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	161
	13:00	235	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	235
	14:00	350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	350
	15:00	312	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	314
	16:00	296	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	296
	17:00	339	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	341
	18:00	355	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	355
	19:00	406	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	406
	20:00	356	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	356
	21:00	184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	184
	22:00	104	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105
	23:00	90	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92
Daily Total :		4089	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4125
Percent :		99%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		170	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33

Speeds - Average: 10.1 50% : 10.1 67% : 13.5 85% : 17.0 10mph Pace: 7.4 - 17.3 (50.7%)

Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
(DEFAULTX)																		
08/12/18	00:00	42	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43
Sun	01:00	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
	02:00	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18
	03:00	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29
	04:00	63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63
	05:00	103	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105
	06:00	77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77
	07:00	102	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	103
	08:00	74	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75
	09:00	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85
	10:00	104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104
	11:00	135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	135
	12:00	152	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	154
	13:00	258	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	259
	14:00	335	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	337
	15:00	326	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	327
	16:00	295	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	296
	17:00	334	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	334
	18:00	321	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	321
	19:00	221	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	221
	20:00	345	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	345
	21:00	184	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	185
	22:00	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
	23:00	79	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80
Daily Total :		3793	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3811
Percent :		100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		158	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	172

Speeds - Average: 10.0 50% : 10.1 67% : 13.5 85% : 17.0 10mph Pace: 8.2 - 18.1 (50.7%)

(DEFAULTX) Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
08/13/18	00:00	38	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41
Mon	01:00	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
	02:00	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
	03:00	32	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33
	04:00	66	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67
	05:00	129	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	131
	06:00	106	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	111
	07:00	105	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	106
	08:00	75	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78
	09:00	91	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93
	10:00	118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	118
	11:00	125	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	129
	12:00	157	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	159
	13:00	217	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	218
	14:00	356	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	357
	15:00	369	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	369
	16:00	357	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	357
	17:00	346	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	347
	18:00	324	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	324
	19:00	347	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	347
	20:00	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54
	21:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	22:00	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
	23:00	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76
Daily Total :		3524	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3551
Percent :		99%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		147	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	159

Speeds - Average: 10.1 50% : 10.1 67% : 13.5 85% : 17.1 10mph Pace: 9.8 - 19.7 (49.9%)

(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
		0.0 -	20.0 -	25.0 -	30.0 -	35.0 -	40.0 -	45.0 -	50.0 -	55.0 -	60.0 -	65.0 -	70.0 -	75.0 -	80.0 -	85.0 -		
Date	Time	19.9	24.9	29.9	34.9	39.9	44.9	49.9	54.9	59.9	64.9	69.9	74.9	79.9	84.9	89.9	Other	Total
08/14/18	00:00	34	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35
Tue	01:00	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
	02:00	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
	03:00	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28
	04:00	50	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52
	05:00	121	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121
	06:00	79	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80
	07:00	99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
	08:00	66	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67
	09:00	86	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88
	10:00	123	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	123
	11:00	127	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	128
	12:00	134	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	137
	13:00	214	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	215
	14:00	287	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	290
	15:00	261	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	262
	16:00	289	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	291
	17:00	325	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	325
	18:00	366	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	366
	19:00	403	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	403
	20:00	272	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	272
	21:00	181	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	181
	22:00	92	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93
	23:00	96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96
Daily Total :		3774	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3794
Percent :		99%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		157	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	148

Speeds - Average: 10.1 50% : 10.1 67% : 13.4 85% : 17.0 10mph Pace: 7.6 - 17.5 (50.9%)

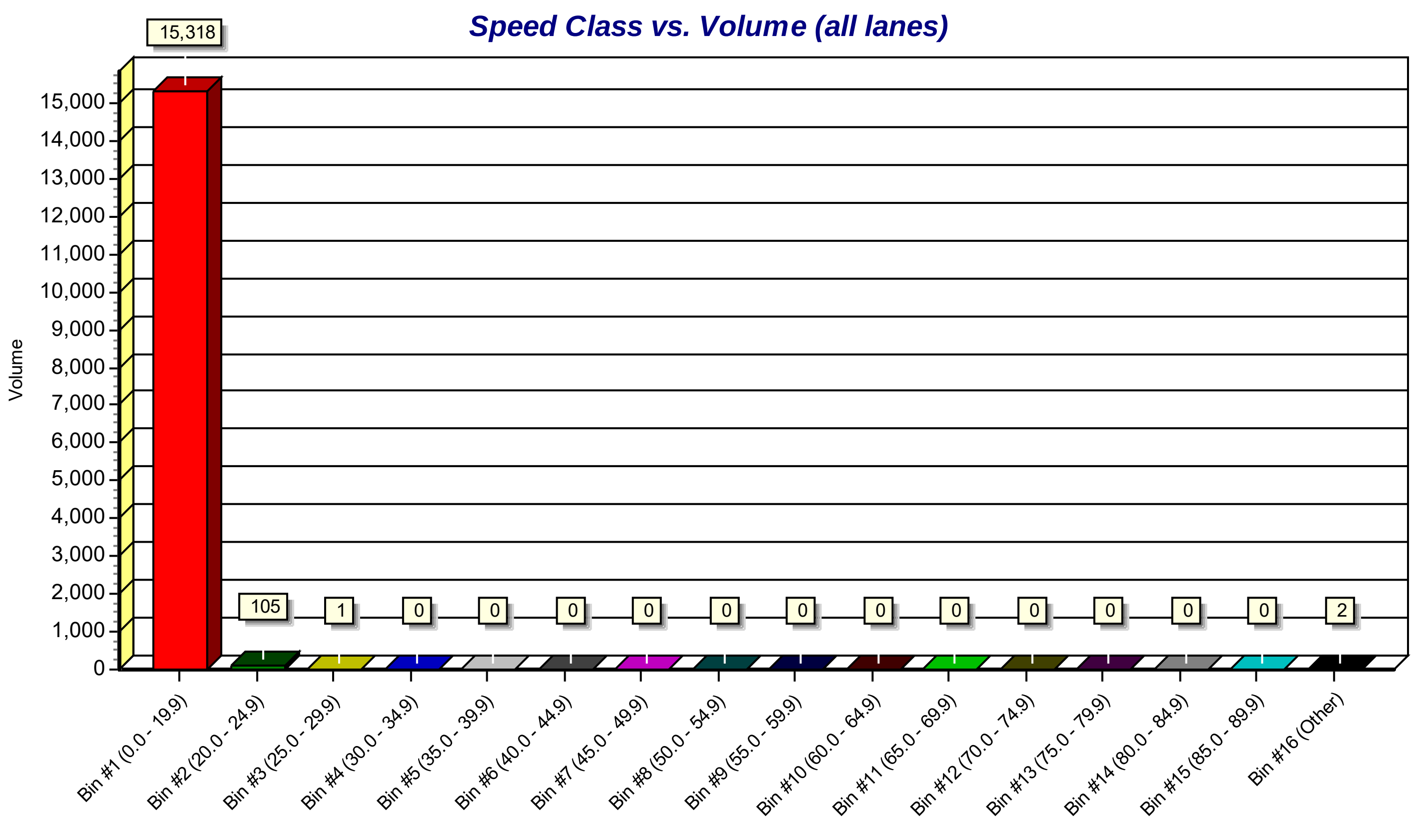
(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
Date	Time	0.0 - 19.9	20.0 - 24.9	25.0 - 29.9	30.0 - 34.9	35.0 - 39.9	40.0 - 44.9	45.0 - 49.9	50.0 - 54.9	55.0 - 59.9	60.0 - 64.9	65.0 - 69.9	70.0 - 74.9	75.0 - 79.9	80.0 - 84.9	85.0 - 89.9	Other	Total
08/15/18	00:00	40	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41
Wed	01:00	20	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23
	02:00	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
Daily Total :		77	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	81
Percent :		95%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		26	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	158

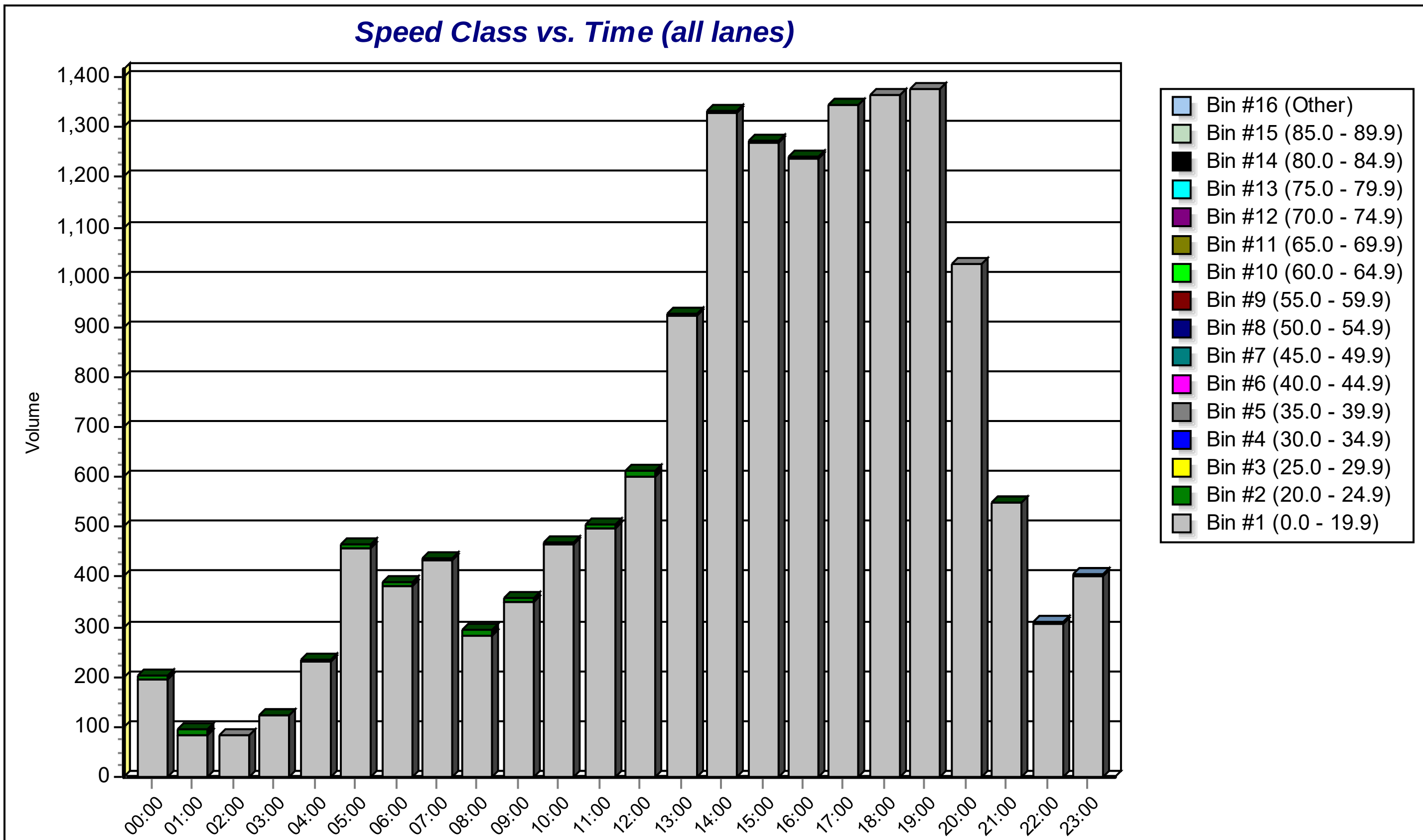
Speeds - Average: 10.6 50% : 10.1 67% : 11.0 85% : 11.9 10mph Pace: 7.6 - 17.5 (95.1%)

Basic Speed Class Summary: 236_046_VHB_ATR 1

(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
Description	Lane	0.0 - 19.9	20.0 - 24.9	25.0 - 29.9	30.0 - 34.9	35.0 - 39.9	40.0 - 44.9	45.0 - 49.9	50.0 - 54.9	55.0 - 59.9	60.0 - 64.9	65.0 - 69.9	70.0 - 74.9	75.0 - 79.9	80.0 - 84.9	85.0 - 89.9	Other	Total
TOTAL COUNT :	#1.	15318	105	1	0	0	0	0	0	0	0	0	0	0	0	0	2	15426
		15318	105	1	0	0	0	0	0	0	0	0	0	0	0	0	2	15426
Percents :	#1.	99%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
		99%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :	#1.	152	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	153
		152	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	153
Days & ADT :	#1.	4.2	3665															
		4.2	3665															
Avg,50,67,85%:	#1.	10.1	10.1	13.5	17.1	7.2	- 17.1	50%										
		10.1	10.1	13.5	17.1	7.2	- 17.1	50%										

236_046_VHB_ATR 1 Speed Class Charts For Data From: 22:00 - 08/10/2018 To: 02:59 - 08/15/2018





Basic Volume Report: 236_046_VHB_ATR 1

Station ID : 236_046_VHB_ATR 1
Info Line 1 : Term E Departure Entry Ramp
Info Line 2 : Logan Airport
GPS Lat/Lon :
DB File : 236046VHBATR 1.DB

Last Connected Device Type : RoadRunner3
Version Number : 1.32
Serial Number : 17749
Number of Lanes : 1
Posted Speed Limit : 0.0 mph

Lane #1 Configuration

#	Dir.	Information	Volume Mode	Volume Sensors	Divide By 2	Comment
1.	N	North	Normal	Veh.	No	

Lane #1 Basic Volume Data From: 21:15 - 08/10/2018 To: 03:14 - 08/15/2018

Date	Time	:00	:15	:30	:45	Total
08/10/18	21:00		0	0	0	0
Fri	22:00	0	0	0	3	3
	23:00	0	17	20	24	61
Day Total :						64

AM Total :		Peak AM Hour :		Peak AM Factor :	Average Period :	5.8
PM Total :	64 (100.0%)	Peak PM Hour : 23:00 =	61 (95.3%)	Peak PM Factor : 0.635	Average Hour :	23.3

Date	Time	:00	:15	:30	:45	Total
08/11/18	00:00	16	16	7	5	44
Sat	01:00	7	5	6	5	23
	02:00	3	3	5	4	15
	03:00	6	7	9	13	35
	04:00	12	11	11	18	52
	05:00	27	22	27	31	107
	06:00	29	31	36	28	124
	07:00	30	33	32	35	130
	08:00	15	28	11	19	73
	09:00	26	10	24	31	91
	10:00	29	32	29	33	123
	11:00	27	25	30	31	113
	12:00	36	35	48	42	161
	13:00	49	46	66	74	235
	14:00	92	80	74	104	350
	15:00	103	82	63	66	314
	16:00	51	81	76	88	296
	17:00	101	75	81	84	341
	18:00	68	95	93	99	355
	19:00	109	106	87	104	406
	20:00	95	91	83	87	356
	21:00	49	51	47	37	184
	22:00	27	34	21	23	105
	23:00	22	29	23	18	92
Day Total :						4125

AM Total :	930 (22.5%)	Peak AM Hour : 07:00 =	130 (3.2%)	Peak AM Factor : 0.903		Average Period :	43.0
PM Total :	3195 (77.5%)	Peak PM Hour : 18:30 =	407 (9.9%)	Peak PM Factor : 0.933		Average Hour :	171.9

Date	Time	:00	:15	:30	:45	Total
08/12/18	00:00	16	13	8	6	43
Sun	01:00	4	5	3	3	15
	02:00	5	5	4	4	18
	03:00	4	5	7	13	29
	04:00	10	15	18	20	63
	05:00	24	34	24	23	105
	06:00	18	19	18	22	77
	07:00	28	28	29	18	103
	08:00	19	20	17	19	75
	09:00	19	18	20	28	85
	10:00	25	30	22	27	104
	11:00	28	30	42	35	135
	12:00	18	48	38	50	154
	13:00	36	80	71	72	259
	14:00	83	83	79	92	337
	15:00	98	75	73	81	327
	16:00	53	76	70	97	296
	17:00	73	78	92	91	334
	18:00	88	61	81	91	321
	19:00	88	61	27	45	221
	20:00	56	99	110	80	345
	21:00	61	65	36	23	185
	22:00	23	24	20	33	100
	23:00	28	19	13	20	80
Day Total :						3811

AM Total :	852 (22.4%)	Peak AM Hour : 11:00 =	135 (3.5%)	Peak AM Factor :	0.804	Average Period :	39.7
PM Total :	2959 (77.6%)	Peak PM Hour : 14:15 =	352 (9.2%)	Peak PM Factor :	0.800	Average Hour :	158.8

Date	Time	:00	:15	:30	:45	Total
08/13/18	00:00	20	10	5	6	41
Mon	01:00	3	3	5	2	13
	02:00	2	3	4	5	14
	03:00	4	7	8	14	33
	04:00	12	10	17	28	67
	05:00	40	20	38	33	131
	06:00	36	25	22	28	111
	07:00	30	27	25	24	106
	08:00	19	26	16	17	78
	09:00	17	22	25	29	93
	10:00	30	22	30	36	118
	11:00	31	32	36	30	129
	12:00	38	44	40	37	159
	13:00	40	60	55	63	218
	14:00	86	92	72	107	357
	15:00	93	96	86	94	369
	16:00	88	87	95	87	357
	17:00	96	92	71	88	347
	18:00	94	82	88	60	324
	19:00	106	83	91	67	347
	20:00	54	0	0	0	54
	21:00	0	0	0	0	0
	22:00	0	0	0	9	9
	23:00	17	17	20	22	76
Day Total :						3551

AM Total :	934 (26.3%)	Peak AM Hour : 10:45 =	135 (3.8%)	Peak AM Factor : 0.844		Average Period :	37.0
PM Total :	2617 (73.7%)	Peak PM Hour : 14:45 =	382 (10.8%)	Peak PM Factor : 0.893		Average Hour :	148.0

Date	Time	:00	:15	:30	:45	Total
08/14/18	00:00	11	11	6	7	35
Tue	01:00	4	8	3	7	22
	02:00	8	3	4	4	19
	03:00	4	6	11	7	28
	04:00	7	17	10	18	52
	05:00	28	27	37	29	121
	06:00	20	22	19	19	80
	07:00	27	26	28	19	100
	08:00	19	13	12	23	67
	09:00	18	16	19	35	88
	10:00	29	26	30	38	123
	11:00	27	31	27	43	128
	12:00	22	34	33	48	137
	13:00	47	41	63	64	215
	14:00	55	77	74	84	290
	15:00	68	66	72	56	262
	16:00	52	69	82	88	291
	17:00	79	80	83	83	325
	18:00	87	80	94	105	366
	19:00	81	110	105	107	403
	20:00	77	66	66	63	272
	21:00	51	55	41	34	181
	22:00	29	24	15	25	93
	23:00	26	25	29	16	96
Day Total :						3794

AM Total :	863 (22.7%)	Peak AM Hour : 11:00 =	128 (3.4%)	Peak AM Factor : 0.744		Average Period :	39.5
PM Total :	2931 (77.3%)	Peak PM Hour : 19:00 =	403 (10.6%)	Peak PM Factor : 0.916		Average Hour :	158.1

Date	Time	:00	:15	:30	:45	Total
08/15/18	00:00	17	11	5	8	41
Wed	01:00	4	6	10	3	23
	02:00	4	4	6	3	17
	03:00	7				7
Day Total :						88

AM Total :	88 (100.0%)	Peak AM Hour : 00:00 =	41 (46.6%)	Peak AM Factor : 0.603		Average Period :	6.8
PM Total :		Peak PM Hour :		Peak PM Factor :		Average Hour :	27.1

Basic Volume Summary: 236_046_VHB_ATR 1

Grand Total For Data From: 21:15 - 08/10/2018 To: 03:14 - 08/15/2018

Lane	*Total Count*		*# Of Days*	*ADT*	*Avg. Period*	*Avg. Hour*	*AM Total & Percent*	*PM Total & Percent*
#1.	15433	(100.0%)	4.25	3631	37.8	151.3	3667 (23.8%)	11766 (76.2%)
ALL	15433		4.25	3631	37.8	151.3	3667 (23.8%)	11766 (76.2%)

Lane	*Peak AM Hour*		*Date*	*Peak AM Factor*	*Peak PM Hour*		*Date*	*Peak PM Factor*
#1.	11:00 =	135	08/12/2018	0.804	18:30 =	407	08/11/2018	0.933

Basic Axle Classification Report: 236_046_VHB_ATR 2

Station ID : 236_046_VHB_ATR 2
Info Line 1 : Term E Dep Exit to Sumner Tunn
Info Line 2 : Logan Airport
GPS Lat/Lon :
DB File : 236046VHBATR 2.DB

Last Connected Device Type : RoadRunner3
Version Number : 1.32
Serial Number : 17750
Number of Lanes : 1
Posted Speed Limit : 0.0 mph

Lane #1 Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length	Comment
1.	W	West	Ax-Ax	3.0 ft	6.0 ft	

Lane #1 Basic Axle Classification Data From: 22:00 - 08/10/2018 To: 03:59 - 08/15/2018

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/10/18	22:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fri	23:00	0	2	0	0	0	0	0	0	0	0	0	0	0	2
Daily Total :		0	2	0	0	0	0	0	0	0	0	0	0	0	2
Percent :		0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		0	1	0	0	0	0	0	0	0	0	0	0	0	1

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/11/18	00:00	2	8	0	0	1	0	0	0	0	0	0	0	0	11
Sat	01:00	0	6	0	0	1	0	0	0	0	0	0	0	0	7
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	03:00	0	6	0	1	0	0	0	0	0	0	0	0	0	7
	04:00	0	10	0	0	0	0	0	0	0	0	0	0	0	10
	05:00	0	31	6	0	0	0	0	0	0	0	0	0	0	37
	06:00	0	48	2	1	1	0	0	0	0	0	0	0	0	52
	07:00	0	37	8	0	0	0	0	0	0	0	0	0	0	45
	08:00	0	17	2	0	1	0	0	0	0	0	0	0	0	20
	09:00	0	21	3	0	1	0	0	0	0	0	0	0	0	25
	10:00	0	32	3	0	0	0	0	0	0	0	0	0	0	35
	11:00	0	29	6	0	1	0	0	0	0	0	0	0	0	36
	12:00	0	38	3	0	2	0	0	0	0	0	0	0	0	43
	13:00	0	66	5	1	0	0	0	0	0	0	0	0	0	72
	14:00	0	120	11	0	0	0	0	0	0	0	0	0	0	131
	15:00	0	96	9	0	0	0	0	0	0	0	0	0	0	105
	16:00	0	69	15	0	0	0	0	0	0	0	0	1	0	85
	17:00	0	99	9	1	1	0	0	0	0	0	0	0	0	110
	18:00	0	124	14	0	0	0	0	0	0	0	0	0	0	138
	19:00	0	121	15	1	3	0	0	0	0	0	0	0	0	140
	20:00	0	109	9	0	1	0	0	0	0	0	0	0	0	119
	21:00	0	70	3	0	3	0	0	0	0	0	0	0	0	76
	22:00	0	44	3	0	2	0	0	0	0	0	0	0	0	49
	23:00	0	22	1	0	0	0	0	0	0	0	0	0	0	23
Daily Total :		2	1223	127	5	18	0	0	0	0	0	0	1	0	1376
Percent :		0%	89%	9%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		0	51	5	0	1	0	0	0	0	0	0	0	0	57

Date	(DEFAULTC) Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/12/18	00:00	0	18	2	0	1	0	0	0	0	0	0	0	0	21
Sun	01:00	0	5	0	0	0	0	0	0	0	0	0	0	0	5
	02:00	0	3	0	0	0	0	0	0	0	0	0	0	0	3
	03:00	0	3	0	0	0	0	0	0	0	0	0	0	0	3
	04:00	0	12	1	1	0	0	0	0	0	0	0	0	0	14
	05:00	0	28	3	0	0	0	0	0	0	0	0	0	0	31
	06:00	0	19	2	0	1	0	0	0	0	0	0	0	0	22
	07:00	0	17	5	0	0	0	0	0	0	0	0	0	0	22
	08:00	0	15	3	0	0	0	0	0	0	0	0	0	0	18
	09:00	0	13	0	0	0	0	0	0	0	0	0	0	0	13
	10:00	0	29	2	0	0	0	0	0	0	0	0	0	0	31
	11:00	0	26	6	0	0	0	0	0	0	0	0	0	0	32
	12:00	0	42	2	0	0	0	0	0	0	0	0	0	0	44
	13:00	0	68	14	0	0	0	0	0	0	0	0	0	0	82
	14:00	0	84	12	1	0	0	0	0	0	0	0	0	0	97
	15:00	0	106	15	0	1	0	0	0	0	0	0	0	0	122
	16:00	0	82	7	0	0	0	0	0	0	0	0	0	0	89
	17:00	0	119	9	0	0	0	0	0	0	0	0	0	0	128
	18:00	0	140	15	0	1	0	0	0	0	0	0	0	0	156
	19:00	0	131	14	0	2	0	0	0	0	0	0	0	0	147
	20:00	0	141	12	0	1	0	0	0	0	0	0	0	0	154
	21:00	0	54	2	0	2	0	0	0	0	0	0	0	0	58
	22:00	0	32	2	0	0	0	0	0	0	0	0	0	0	34
	23:00	0	36	2	0	0	0	0	0	0	0	0	0	0	38
Daily Total :		0	1223	130	2	9	0	0	0	0	0	0	0	0	1364
Percent :		0%	90%	10%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		0	51	5	0	0	0	0	0	0	0	0	0	0	56

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/13/18	00:00	0	19	2	0	1	0	0	0	0	0	0	0	0	22
Mon	01:00	0	3	0	0	0	0	0	0	0	0	0	0	0	3
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	03:00	0	3	1	0	0	0	0	0	0	0	0	0	0	4
	04:00	0	13	1	1	0	0	0	0	0	0	0	0	0	15
	05:00	0	48	4	1	0	0	0	0	0	0	0	0	0	53
	06:00	0	26	4	1	1	0	0	0	0	0	0	0	0	32
	07:00	0	33	4	3	2	0	0	0	0	0	0	0	0	42
	08:00	0	9	0	1	0	0	0	0	0	0	0	0	0	10
	09:00	0	15	1	2	0	0	0	0	0	0	0	0	0	18
	10:00	0	18	2	0	0	0	0	0	0	0	0	0	0	20
	11:00	0	23	3	0	1	0	0	0	0	0	0	0	0	27
	12:00	0	30	5	0	0	0	0	0	0	0	0	0	0	35
	13:00	0	60	3	0	2	0	0	0	0	0	0	0	0	65
	14:00	0	101	5	0	1	0	0	1	0	0	0	0	0	108
	15:00	0	109	10	2	0	0	0	0	0	0	0	0	0	121
	16:00	0	104	11	0	1	0	0	0	0	0	0	0	0	116
	17:00	0	111	17	1	0	0	0	0	0	0	0	0	0	129
	18:00	0	112	12	1	0	0	0	0	0	0	0	0	0	125
	19:00	0	130	12	0	2	0	0	0	0	0	0	0	0	144
	20:00	0	96	6	0	1	0	0	0	0	0	0	0	0	103
	21:00	0	77	7	0	1	0	0	0	0	0	0	0	0	85
	22:00	0	33	3	0	0	0	0	0	0	0	0	0	0	36
	23:00	0	22	3	0	0	0	0	0	0	0	0	0	0	25
Daily Total :		0	1195	116	13	13	0	0	1	0	0	0	0	0	1338
Percent :		0%	89%	9%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		0	50	5	1	1	0	0	0	0	0	0	0	0	57

Date	(DEFAULTC) Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/14/18	00:00	0	17	0	0	0	0	0	0	0	0	0	0	0	17
Tue	01:00	0	7	0	0	0	0	0	0	0	0	0	0	0	7
	02:00	0	5	0	0	0	0	0	0	0	0	0	0	0	5
	03:00	0	4	2	0	0	0	0	0	0	0	0	0	0	6
	04:00	0	11	0	2	0	0	0	0	0	0	0	0	0	13
	05:00	0	30	8	2	0	0	0	0	0	0	0	0	0	40
	06:00	0	25	0	1	1	0	0	0	0	0	0	0	0	27
	07:00	0	16	6	2	1	0	0	0	0	0	0	0	0	25
	08:00	0	12	3	2	1	0	0	0	0	0	0	0	0	18
	09:00	0	14	8	0	0	0	0	0	0	0	0	0	0	22
	10:00	0	31	0	0	0	1	0	0	0	0	0	0	0	32
	11:00	0	30	4	1	3	0	0	0	0	0	0	0	0	38
	12:00	0	27	0	0	0	0	0	0	0	0	0	0	0	27
	13:00	0	47	5	0	0	0	0	1	0	0	0	0	0	53
	14:00	0	86	4	0	0	0	0	0	0	0	0	0	0	90
	15:00	0	88	5	0	0	0	0	0	0	0	0	0	0	93
	16:00	0	82	11	0	1	0	0	0	0	0	0	0	0	94
	17:00	0	94	9	0	0	0	0	0	0	0	0	0	0	103
	18:00	0	105	13	0	0	0	0	0	0	0	0	0	0	118
	19:00	0	138	19	0	0	0	0	1	0	0	0	0	0	158
	20:00	0	73	9	0	0	0	0	0	0	0	0	0	0	82
	21:00	0	64	5	0	2	0	0	0	0	0	0	0	0	71
	22:00	0	32	2	0	0	0	0	0	0	0	0	0	0	34
	23:00	0	33	2	0	0	0	0	0	0	0	0	0	0	35
Daily Total :		0	1071	115	10	9	1	0	2	0	0	0	0	0	1208
Percent :		0%	89%	10%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		0	45	5	0	0	0	0	0	0	0	0	0	0	50

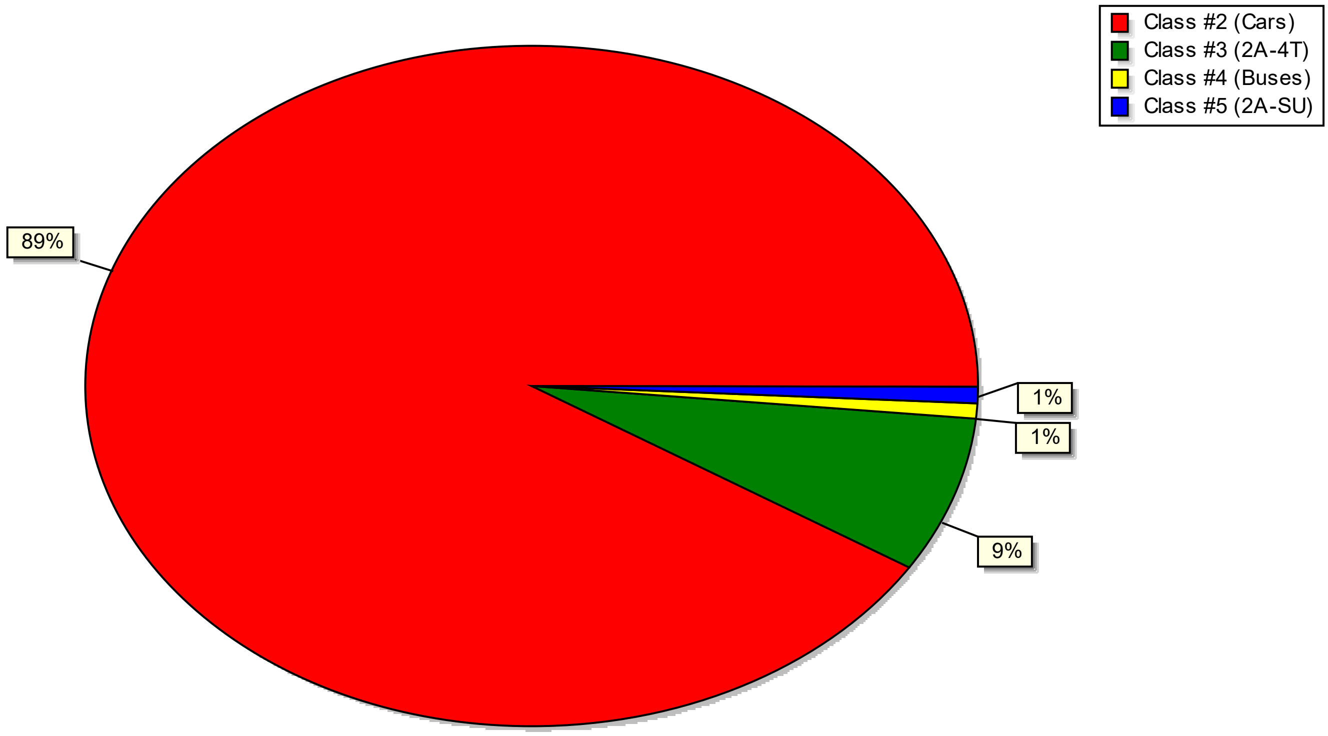
(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/15/18	00:00	0	16	1	0	1	0	0	0	0	0	0	0	0	18
Wed	01:00	0	9	0	0	0	0	0	0	0	0	0	0	0	9
	02:00	0	5	0	0	0	0	0	0	0	0	0	0	0	5
	03:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		0	30	1	0	1	0	0	0	0	0	0	0	0	32
Percent :		0%	94%	3%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		0	8	0	0	0	0	0	0	0	0	0	0	0	8

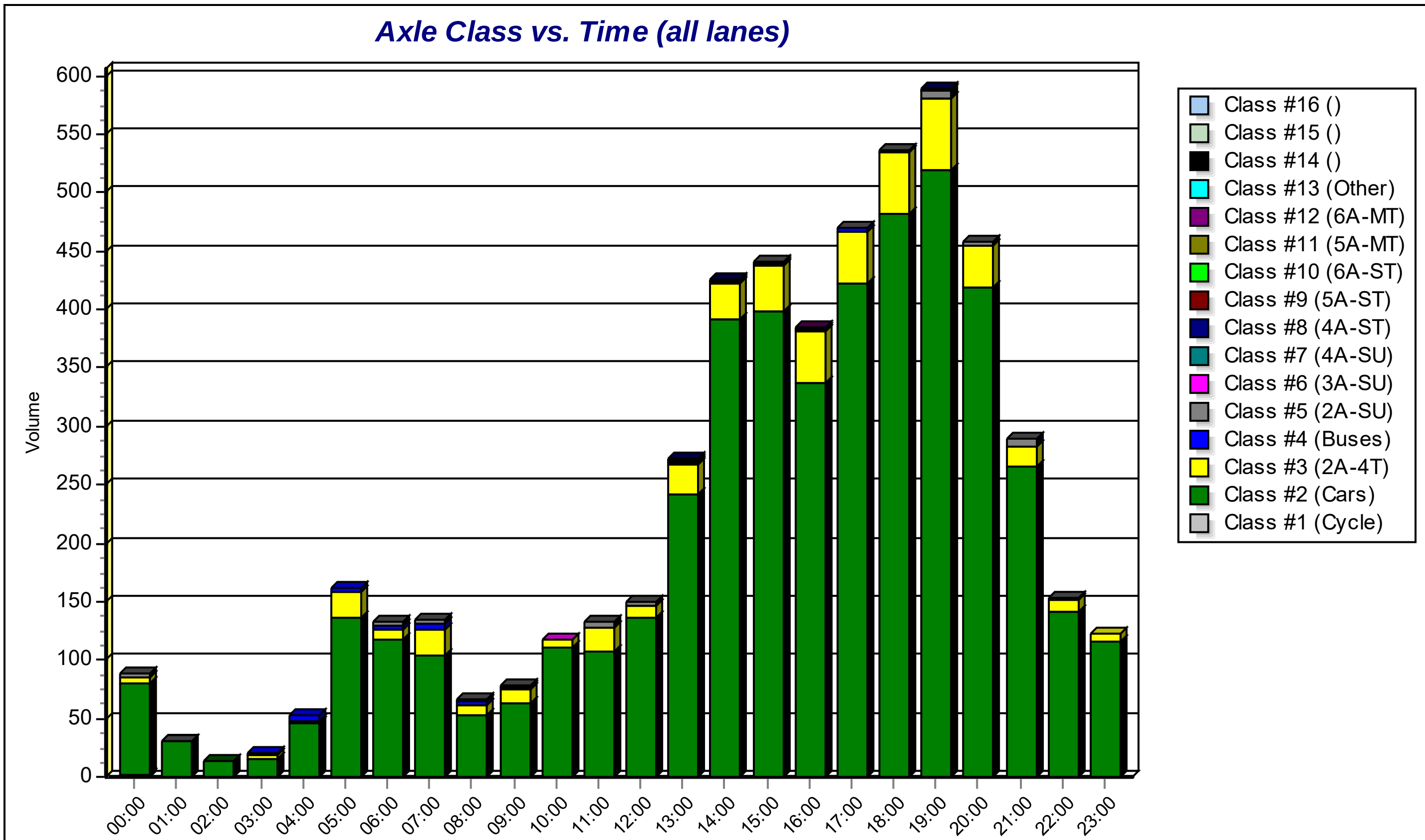
Basic Axle Class Summary: 236_046_VHB_ATR 2

(DEFAULTC) Description	Lane	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
TOTAL COUNT :	#1.	2	4744	489	30	50	1	0	3	0	0	0	1	0	5320
		2	4744	489	30	50	1	0	3	0	0	0	1	0	5320
Percents :	#1.	0%	89%	9%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	100%
		0%	89%	9%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :	#1.	0	47	5	0	0	0	0	0	0	0	0	0	0	52
		0	47	5	0	0	0	0	0	0	0	0	0	0	52
Days & ADT :	#1.	4.2	1251												
		4.2	1251												

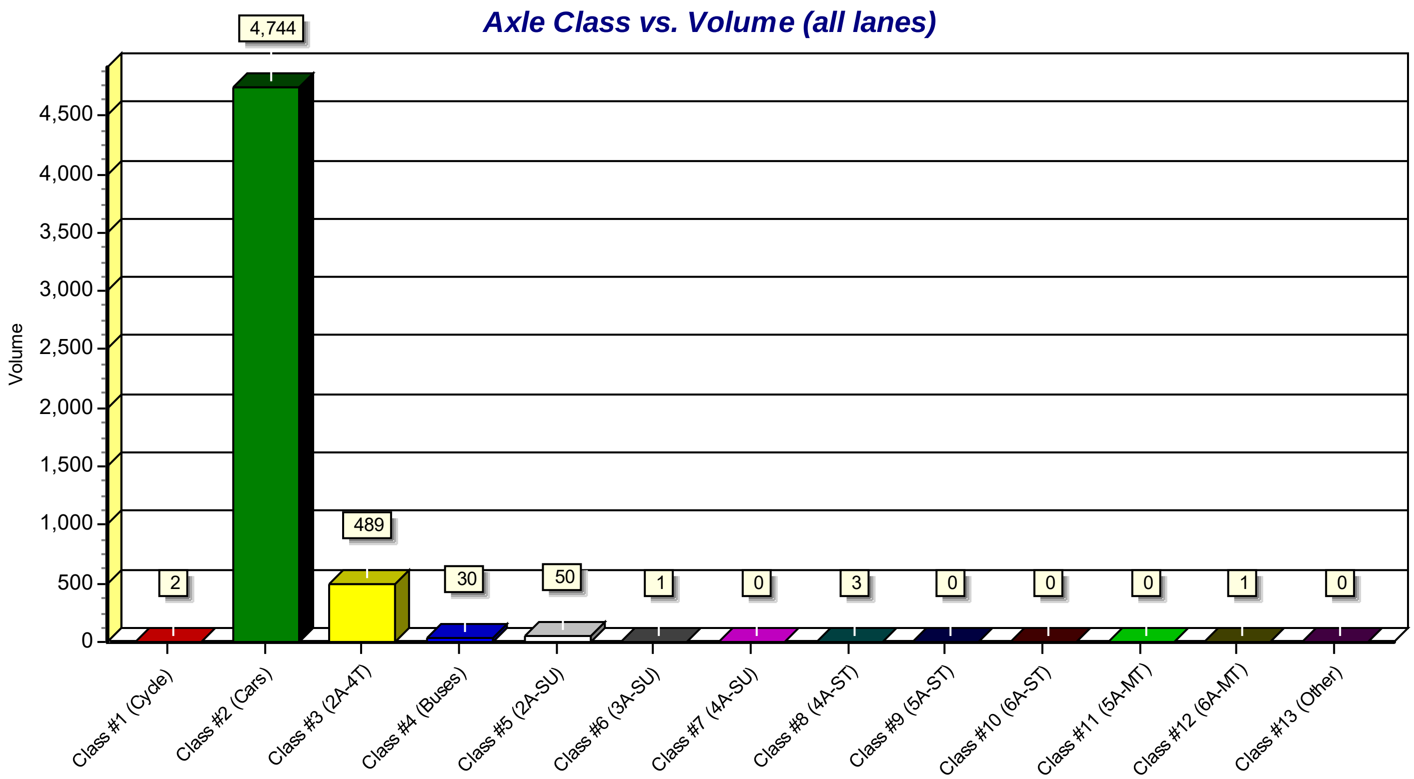
236_046_VHB_ATR 2 Axle Class Charts For Data From: 22:00 - 08/10/2018 To: 03:59 - 08/15/2018

Axle Class Percentages:





236_046_VHB_ATR 2 Axle Class Charts For Data From: 22:00 - 08/10/2018 To: 03:59 - 08/15/2018



Basic Speed Classification Report: 236_046_VHB_ATR

Lane #1 Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length	Comment
1.	W	West	Ax-Ax	3.0 ft	6.0 ft	

Lane #1 Basic Speed Classification Data From: 22:00 - 08/10/2018 To: 03:59 - 08/15/2018

(DEFAULTX) Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
08/10/18	22:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fri	23:00	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2
Daily Total :		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2
Percent :		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%	0%	0%	0%	0%	50%	
Average :		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	52

Speeds - Average: 33.7 50% : 67.5 67% : 67.5 85% : 67.5 10mph Pace: 67.5 - 77.4 (50.0%)

Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
(DEFAULTX)																		
08/11/18	00:00	7	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	11
Sat	01:00	0	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	7
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	03:00	1	1	2	3	0	0	0	0	0	0	0	0	0	0	0	0	7
	04:00	0	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	10
	05:00	2	9	18	8	0	0	0	0	0	0	0	0	0	0	0	0	37
	06:00	1	15	23	11	2	0	0	0	0	0	0	0	0	0	0	0	52
	07:00	1	12	25	6	1	0	0	0	0	0	0	0	0	0	0	0	45
	08:00	3	4	12	1	0	0	0	0	0	0	0	0	0	0	0	0	20
	09:00	0	6	11	8	0	0	0	0	0	0	0	0	0	0	0	0	25
	10:00	3	11	12	7	2	0	0	0	0	0	0	0	0	0	0	0	35
	11:00	0	15	19	2	0	0	0	0	0	0	0	0	0	0	0	0	36
	12:00	3	13	23	3	1	0	0	0	0	0	0	0	0	0	0	0	43
	13:00	5	24	37	6	0	0	0	0	0	0	0	0	0	0	0	0	72
	14:00	7	30	70	22	2	0	0	0	0	0	0	0	0	0	0	0	131
	15:00	4	34	49	15	3	0	0	0	0	0	0	0	0	0	0	0	105
	16:00	6	27	43	7	2	0	0	0	0	0	0	0	0	0	0	0	85
	17:00	7	33	59	9	2	0	0	0	0	0	0	0	0	0	0	0	110
	18:00	3	47	64	23	1	0	0	0	0	0	0	0	0	0	0	0	138
	19:00	13	49	63	15	0	0	0	0	0	0	0	0	0	0	0	0	140
	20:00	11	41	56	11	0	0	0	0	0	0	0	0	0	0	0	0	119
	21:00	7	30	31	7	1	0	0	0	0	0	0	0	0	0	0	0	76
	22:00	2	16	24	6	1	0	0	0	0	0	0	0	0	0	0	0	49
	23:00	5	3	10	5	0	0	0	0	0	0	0	0	0	0	0	0	23
Daily Total :		91	428	657	180	20	0	0	0	0	0	0	0	0	0	0	0	1376
Percent :		7%	31%	48%	13%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		4	18	27	8	1	0	0	0	0	0	0	0	0	0	0	0	2

Speeds - Average: 25.5 50% : 26.4 67% : 28.0 85% : 30.0 10mph Pace: 20.1 - 30.0 (79.1%)

(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
		0.0 -	20.0 -	25.0 -	30.0 -	35.0 -	40.0 -	45.0 -	50.0 -	55.0 -	60.0 -	65.0 -	70.0 -	75.0 -	80.0 -	85.0 -		
Date	Time	19.9	24.9	29.9	34.9	39.9	44.9	49.9	54.9	59.9	64.9	69.9	74.9	79.9	84.9	89.9	Other	Total
08/12/18	00:00	3	2	12	3	1	0	0	0	0	0	0	0	0	0	0	0	21
Sun	01:00	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	5
	02:00	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	3
	03:00	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	04:00	3	2	3	5	1	0	0	0	0	0	0	0	0	0	0	0	14
	05:00	4	6	17	4	0	0	0	0	0	0	0	0	0	0	0	0	31
	06:00	1	11	7	3	0	0	0	0	0	0	0	0	0	0	0	0	22
	07:00	0	7	13	2	0	0	0	0	0	0	0	0	0	0	0	0	22
	08:00	0	4	12	2	0	0	0	0	0	0	0	0	0	0	0	0	18
	09:00	2	2	6	3	0	0	0	0	0	0	0	0	0	0	0	0	13
	10:00	5	5	19	2	0	0	0	0	0	0	0	0	0	0	0	0	31
	11:00	1	6	18	7	0	0	0	0	0	0	0	0	0	0	0	0	32
	12:00	5	6	27	5	1	0	0	0	0	0	0	0	0	0	0	0	44
	13:00	9	16	38	18	1	0	0	0	0	0	0	0	0	0	0	0	82
	14:00	4	27	46	20	0	0	0	0	0	0	0	0	0	0	0	0	97
	15:00	5	22	71	22	2	0	0	0	0	0	0	0	0	0	0	0	122
	16:00	2	30	45	11	1	0	0	0	0	0	0	0	0	0	0	0	89
	17:00	7	27	73	18	3	0	0	0	0	0	0	0	0	0	0	0	128
	18:00	6	49	67	33	1	0	0	0	0	0	0	0	0	0	0	0	156
	19:00	10	47	62	25	3	0	0	0	0	0	0	0	0	0	0	0	147
	20:00	7	53	65	27	2	0	0	0	0	0	0	0	0	0	0	0	154
	21:00	2	23	27	5	1	0	0	0	0	0	0	0	0	0	0	0	58
	22:00	0	6	25	3	0	0	0	0	0	0	0	0	0	0	0	0	34
	23:00	9	11	17	0	1	0	0	0	0	0	0	0	0	0	0	0	38
Daily Total :		85	364	677	219	19	0	0	0	0	0	0	0	0	0	0	0	1364
Percent :		6%	27%	50%	16%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		4	15	28	9	1	0	0	0	0	0	0	0	0	0	0	0	58

Speeds - Average: 26.0 50% : 26.8 67% : 28.4 85% : 30.9 10mph Pace: 20.1 - 30.0 (76.6%)

(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
Date	Time	0.0 - 19.9	20.0 - 24.9	25.0 - 29.9	30.0 - 34.9	35.0 - 39.9	40.0 - 44.9	45.0 - 49.9	50.0 - 54.9	55.0 - 59.9	60.0 - 64.9	65.0 - 69.9	70.0 - 74.9	75.0 - 79.9	80.0 - 84.9	85.0 - 89.9	Other	Total
08/13/18	00:00	3	3	14	2	0	0	0	0	0	0	0	0	0	0	0	0	22
Mon	01:00	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	03:00	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	4
	04:00	0	6	8	1	0	0	0	0	0	0	0	0	0	0	0	0	15
	05:00	6	10	26	7	4	0	0	0	0	0	0	0	0	0	0	0	53
	06:00	2	12	11	7	0	0	0	0	0	0	0	0	0	0	0	0	32
	07:00	5	10	22	5	0	0	0	0	0	0	0	0	0	0	0	0	42
	08:00	0	1	7	2	0	0	0	0	0	0	0	0	0	0	0	0	10
	09:00	0	3	8	7	0	0	0	0	0	0	0	0	0	0	0	0	18
	10:00	0	3	10	6	1	0	0	0	0	0	0	0	0	0	0	0	20
	11:00	3	6	10	8	0	0	0	0	0	0	0	0	0	0	0	0	27
	12:00	1	8	16	10	0	0	0	0	0	0	0	0	0	0	0	0	35
	13:00	1	22	29	13	0	0	0	0	0	0	0	0	0	0	0	0	65
	14:00	7	26	48	25	2	0	0	0	0	0	0	0	0	0	0	0	108
	15:00	3	29	66	21	2	0	0	0	0	0	0	0	0	0	0	0	121
	16:00	4	38	51	21	2	0	0	0	0	0	0	0	0	0	0	0	116
	17:00	5	40	71	12	1	0	0	0	0	0	0	0	0	0	0	0	129
	18:00	12	43	50	19	0	1	0	0	0	0	0	0	0	0	0	0	125
	19:00	9	37	69	26	2	1	0	0	0	0	0	0	0	0	0	0	144
	20:00	8	34	47	12	2	0	0	0	0	0	0	0	0	0	0	0	103
	21:00	15	30	32	8	0	0	0	0	0	0	0	0	0	0	0	0	85
	22:00	4	11	15	5	1	0	0	0	0	0	0	0	0	0	0	0	36
	23:00	6	7	8	3	1	0	0	0	0	0	0	0	0	0	0	0	25
Daily Total :		94	381	622	221	18	2	0	0	0	0	0	0	0	0	0	0	1338
Percent :		7%	28%	46%	17%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		4	16	26	9	1	0	0	0	0	0	0	0	0	0	0	0	57

Speeds - Average: 25.8 50% : 26.6 67% : 28.4 85% : 31.0 10mph Pace: 20.1 - 30.0 (75.3%)

(DEFAULTX) Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
08/14/18	00:00	0	10	5	2	0	0	0	0	0	0	0	0	0	0	0	0	17
Tue	01:00	1	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	7
	02:00	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	5
	03:00	0	0	4	1	1	0	0	0	0	0	0	0	0	0	0	0	6
	04:00	0	3	7	3	0	0	0	0	0	0	0	0	0	0	0	0	13
	05:00	0	10	19	10	1	0	0	0	0	0	0	0	0	0	0	0	40
	06:00	1	8	13	4	1	0	0	0	0	0	0	0	0	0	0	0	27
	07:00	2	8	12	2	1	0	0	0	0	0	0	0	0	0	0	0	25
	08:00	0	9	7	2	0	0	0	0	0	0	0	0	0	0	0	0	18
	09:00	0	3	13	6	0	0	0	0	0	0	0	0	0	0	0	0	22
	10:00	3	6	17	6	0	0	0	0	0	0	0	0	0	0	0	0	32
	11:00	1	10	18	7	2	0	0	0	0	0	0	0	0	0	0	0	38
	12:00	4	5	10	8	0	0	0	0	0	0	0	0	0	0	0	0	27
	13:00	5	16	24	8	0	0	0	0	0	0	0	0	0	0	0	0	53
	14:00	5	22	41	17	4	1	0	0	0	0	0	0	0	0	0	0	90
	15:00	8	27	38	17	3	0	0	0	0	0	0	0	0	0	0	0	93
	16:00	3	26	41	22	2	0	0	0	0	0	0	0	0	0	0	0	94
	17:00	8	17	57	20	1	0	0	0	0	0	0	0	0	0	0	0	103
	18:00	3	30	60	23	2	0	0	0	0	0	0	0	0	0	0	0	118
	19:00	10	45	72	29	2	0	0	0	0	0	0	0	0	0	0	0	158
	20:00	4	25	36	16	1	0	0	0	0	0	0	0	0	0	0	0	82
	21:00	8	25	30	8	0	0	0	0	0	0	0	0	0	0	0	0	71
	22:00	2	6	18	8	0	0	0	0	0	0	0	0	0	0	0	0	34
	23:00	5	13	13	3	1	0	0	0	0	0	0	0	0	0	0	0	35
Daily Total :		73	329	558	225	22	1	0	0	0	0	0	0	0	0	0	0	1208
Percent :		6%	27%	46%	19%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		3	14	23	9	1	0	0	0	0	0	0	0	0	0	0	0	56

Speeds - Average: 26.2 50% : 26.8 67% : 28.6 85% : 31.5 10mph Pace: 20.1 - 30.0 (73.8%)

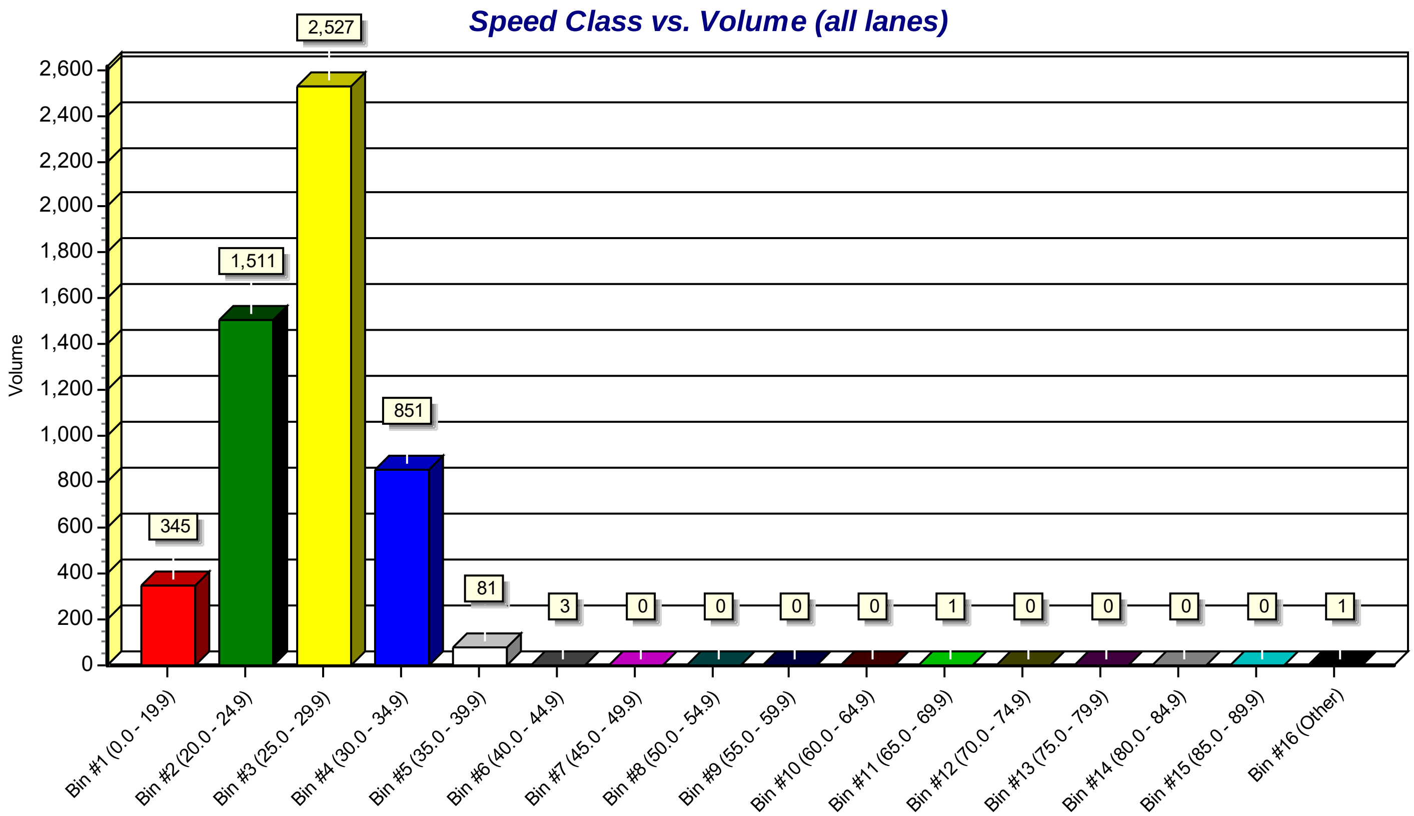
(DEFAULTX) Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
08/15/18	00:00	2	4	7	4	1	0	0	0	0	0	0	0	0	0	0	0	18
Wed	01:00	0	2	5	1	1	0	0	0	0	0	0	0	0	0	0	0	9
	02:00	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	5
	03:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		2	9	13	6	2	0	0	0	0	0	0	0	0	0	0	0	32
Percent :		6%	28%	41%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		1	2	3	2	1	0	0	0	0	0	0	0	0	0	0	0	50

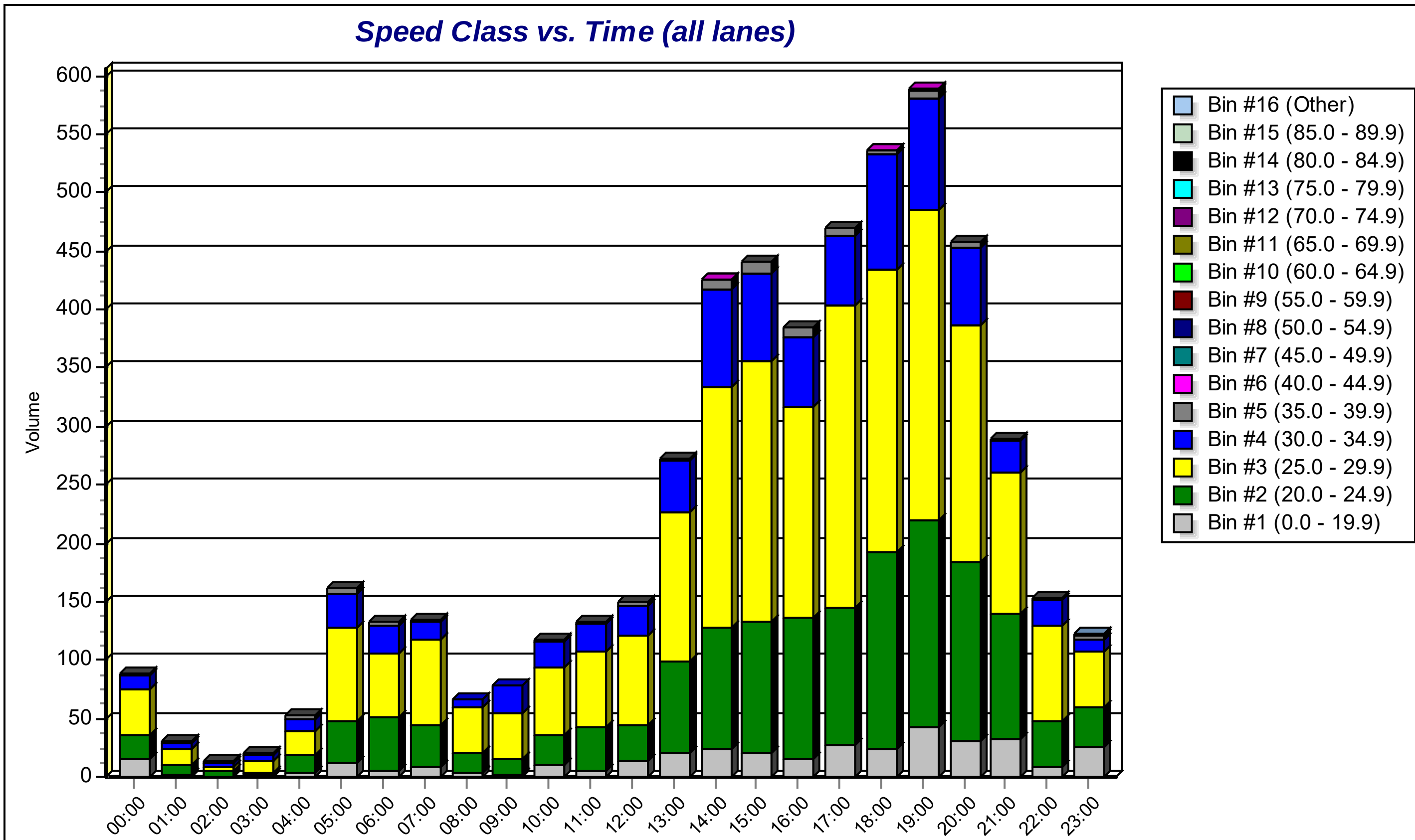
Speeds - Average: 26.5 50% : 27.4 67% : 27.7 85% : 32.5 10mph Pace: 22.2 - 32.1 (68.8%)

Basic Speed Class Summary: 236_046_VHB_ATR 2

(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
Description	Lane	0.0 - 19.9	20.0 - 24.9	25.0 - 29.9	30.0 - 34.9	35.0 - 39.9	40.0 - 44.9	45.0 - 49.9	50.0 - 54.9	55.0 - 59.9	60.0 - 64.9	65.0 - 69.9	70.0 - 74.9	75.0 - 79.9	80.0 - 84.9	85.0 - 89.9	Other	Total
TOTAL COUNT :	#1.	345	1511	2527	851	81	3	0	0	0	0	1	0	0	0	0	1	5320
		345	1511	2527	851	81	3	0	0	0	0	1	0	0	0	0	1	5320
Percents :	#1.	6%	28%	48%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
		6%	28%	48%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :	#1.	3	15	25	8	1	0	0	0	0	0	0	0	0	0	0	0	52
		3	15	25	8	1	0	0	0	0	0	0	0	0	0	0	0	52
Days & ADT :	#1.	4.2	1251															
		4.2	1251															
Avg,50,67,85%:	#1.	25.8	26.7	28.4	30.8	20.1	- 30.0	76%										
		25.8	26.7	28.4	30.8	20.1	- 30.0	76%										

236_046_VHB_ATR 2 Speed Class Charts For Data From: 22:00 - 08/10/2018 To: 03:59 - 08/15/2018





Basic Volume Report: 236_046_VHB_ATR 2

Station ID : 236_046_VHB_ATR 2
Info Line 1 : Term E Dep Exit to Sumner Tunn
Info Line 2 : Logan Airport
GPS Lat/Lon :
DB File : 236046VHBATR 2.DB

Last Connected Device Type : RoadRunner3
Version Number : 1.32
Serial Number : 17750
Number of Lanes : 1
Posted Speed Limit : 0.0 mph

Lane #1 Configuration

#	Dir.	Information	Volume Mode	Volume Sensors	Divide By 2	Comment
1.	W	West	Normal	Veh.	No	

Lane #1 Basic Volume Data From: 21:15 - 08/10/2018 To: 04:59 - 08/15/2018

Date	Time	:00	:15	:30	:45	Total
08/10/18	21:00		0	0	0	0
Fri	22:00	0	0	0	0	0
	23:00	0	0	2	0	2
Day Total :						2

AM Total :		Peak AM Hour :		Peak AM Factor :	Average Period :	0.2
PM Total :	2 (100.0%)	Peak PM Hour : 22:45 =	2 (100.0%)	Peak PM Factor : 0.250	Average Hour :	0.7

Date	Time	:00	:15	:30	:45	Total
08/11/18	00:00	3	3	4	1	11
Sat	01:00	2	1	2	2	7
	02:00	0	0	0	0	0
	03:00	1	1	1	4	7
	04:00	4	1	2	3	10
	05:00	4	12	10	11	37
	06:00	13	11	18	10	52
	07:00	11	10	13	11	45
	08:00	8	7	2	3	20
	09:00	3	2	6	14	25
	10:00	9	8	13	5	35
	11:00	12	7	5	12	36
	12:00	6	7	14	16	43
	13:00	16	16	18	22	72
	14:00	28	29	32	42	131
	15:00	27	30	30	18	105
	16:00	16	19	22	28	85
	17:00	28	31	22	29	110
	18:00	27	31	46	34	138
	19:00	33	42	35	30	140
	20:00	25	40	22	32	119
	21:00	19	20	22	15	76
	22:00	14	8	14	13	49
	23:00	6	5	8	4	23
Day Total :						1376

AM Total :	285 (20.7%)	Peak AM Hour : 05:45 =	53 (3.9%)	Peak AM Factor : 0.736		Average Period :	14.3
PM Total :	1091 (79.3%)	Peak PM Hour : 18:30 =	155 (11.3%)	Peak PM Factor : 0.842		Average Hour :	57.3

Date	Time	:00	:15	:30	:45	Total
08/12/18	00:00	5	6	5	5	21
Sun	01:00	0	3	1	1	5
	02:00	1	2	0	0	3
	03:00	0	2	0	1	3
	04:00	1	4	7	2	14
	05:00	7	7	9	8	31
	06:00	5	6	4	7	22
	07:00	6	4	6	6	22
	08:00	4	6	3	5	18
	09:00	4	2	3	4	13
	10:00	8	10	7	6	31
	11:00	7	7	10	8	32
	12:00	9	10	13	12	44
	13:00	12	27	21	22	82
	14:00	13	26	25	33	97
	15:00	38	26	24	34	122
	16:00	15	18	23	33	89
	17:00	31	31	32	34	128
	18:00	30	41	40	45	156
	19:00	40	42	30	35	147
	20:00	56	42	29	27	154
	21:00	14	22	15	7	58
	22:00	8	9	11	6	34
	23:00	13	10	8	7	38
Day Total :						1364

AM Total :	215 (15.8%)	Peak AM Hour : 11:00 =	32 (2.3%)	Peak AM Factor : 0.800		Average Period :	14.2
PM Total :	1149 (84.2%)	Peak PM Hour : 18:30 =	167 (12.2%)	Peak PM Factor : 0.746		Average Hour :	56.8

Date	Time	:00	:15	:30	:45	Total
08/13/18	00:00	11	7	3	1	22
Mon	01:00	1	1	1	0	3
	02:00	0	0	0	0	0
	03:00	0	0	1	3	4
	04:00	3	2	2	8	15
	05:00	16	11	17	9	53
	06:00	11	9	7	5	32
	07:00	12	11	13	6	42
	08:00	4	1	2	3	10
	09:00	5	2	3	8	18
	10:00	6	2	5	7	20
	11:00	2	8	7	10	27
	12:00	11	7	11	6	35
	13:00	11	20	18	16	65
	14:00	21	27	21	39	108
	15:00	25	32	36	28	121
	16:00	27	23	32	34	116
	17:00	36	36	28	29	129
	18:00	31	31	27	36	125
	19:00	36	40	35	33	144
	20:00	30	22	32	19	103
	21:00	26	21	18	20	85
	22:00	14	9	6	7	36
	23:00	8	7	3	7	25
Day Total :						1338

AM Total :	246 (18.4%)	Peak AM Hour : 05:00 =	53 (4.0%)	Peak AM Factor :	0.779	Average Period :	13.9
PM Total :	1092 (81.6%)	Peak PM Hour : 18:45 =	147 (11.0%)	Peak PM Factor :	0.919	Average Hour :	55.8

Date	Time	:00	:15	:30	:45	Total
08/14/18	00:00	6	5	4	2	17
Tue	01:00	1	1	2	3	7
	02:00	1	4	0	0	5
	03:00	0	1	5	0	6
	04:00	2	4	3	4	13
	05:00	8	9	16	7	40
	06:00	9	4	5	9	27
	07:00	4	8	7	6	25
	08:00	3	6	4	5	18
	09:00	4	4	3	11	22
	10:00	9	7	7	9	32
	11:00	10	9	5	14	38
	12:00	3	4	9	11	27
	13:00	14	15	11	13	53
	14:00	14	27	23	26	90
	15:00	31	23	21	18	93
	16:00	15	25	26	28	94
	17:00	31	17	23	32	103
	18:00	22	22	35	39	118
	19:00	44	44	41	29	158
	20:00	21	23	18	20	82
	21:00	14	21	18	18	71
	22:00	17	6	3	8	34
	23:00	9	6	8	12	35
Day Total :						1208

AM Total :	250 (20.7%)	Peak AM Hour : 05:15 =	41 (3.4%)	Peak AM Factor :	0.641	Average Period :	12.6
PM Total :	958 (79.3%)	Peak PM Hour : 18:45 =	168 (13.9%)	Peak PM Factor :	0.955	Average Hour :	50.3

Date	Time	:00	:15	:30	:45	Total
08/15/18	00:00	5	7	4	2	18
Wed	01:00	1	1	6	1	9
	02:00	0	1	1	3	5
	03:00	0	0	0	0	0
	04:00	0	0	0		0
Day Total :						32

AM Total :	32 (100.0%)	Peak AM Hour : 00:00 =	18 (56.3%)	Peak AM Factor :	0.643	Average Period :	1.7
PM Total :		Peak PM Hour :		Peak PM Factor :		Average Hour :	6.7

Basic Volume Summary: 236_046_VHB_ATR 2

Grand Total For Data From: 21:15 - 08/10/2018   To: 04:59 - 08/15/2018

Lane	Total Count		# Of Days	ADT	Avg. Period	Avg. Hour	AM Total & Percent	PM Total & Percent
#1.	5320	(100.0%)	4.31	1234	12.9	51.4	1028 (19.3%)	4292 (80.7%)
ALL	5320		4.31	1234	12.9	51.4	1028 (19.3%)	4292 (80.7%)

Lane	Peak AM Hour		Date	Peak AM Factor	Peak PM Hour		Date	Peak PM Factor
#1.	05:45 =	53	08/11/2018	0.736	18:45 =	168	08/14/2018	0.955

Basic Axle Classification Report: 236_046_VHB_ATR 9

Station ID : 236_046_VHB_ATR 9
Info Line 1 : C-E Conn Roadway, before Badge
Info Line 2 : Logan Airport
GPS Lat/Lon :
DB File : 236046VHBATR 9.DB

Last Connected Device Type : RoadRunner3
Version Number : 1.32
Serial Number : 17748
Number of Lanes : 1
Posted Speed Limit : 0.0 mph

Lane #1 Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length	Comment
1.	W	West	Ax-Ax	3.0 ft	6.0 ft	

Lane #1 Basic Axle Classification Data From: 22:00 - 08/10/2018 To: 02:59 - 08/15/2018

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/10/18	22:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fri	23:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Percent :		-	-	-	-	-	-	-	-	-	-	-	-	-	
Average :		0	0	0	0	0	0	0	0	0	0	0	0	0	0

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/11/18	00:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sat	01:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	03:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	04:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	05:00	0	16	8	4	1	0	1	4	0	0	0	0	0	34
	06:00	1	34	21	10	3	0	0	7	0	0	0	0	1	77
	07:00	0	48	24	14	2	0	0	6	1	1	0	0	0	96
	08:00	3	50	23	11	2	0	0	8	0	0	0	0	1	98
	09:00	0	42	17	17	1	1	0	3	0	0	0	0	0	81
	10:00	0	39	17	14	2	1	0	8	1	1	0	0	1	84
	11:00	1	42	14	23	3	0	0	5	0	0	0	0	0	88
	12:00	2	38	30	13	2	0	0	4	0	0	0	0	1	90
	13:00	1	27	26	25	3	4	0	3	1	0	0	0	1	91
	14:00	0	68	20	24	4	1	1	6	1	0	0	0	0	125
	15:00	4	75	26	23	2	0	0	8	0	0	1	1	0	140
	16:00	1	56	28	19	1	3	1	7	0	0	0	1	0	117
	17:00	5	75	20	14	3	4	1	4	0	0	1	0	0	127
	18:00	3	99	24	18	5	2	1	10	1	1	1	1	8	174
	19:00	0	98	22	21	1	3	1	12	1	0	1	0	5	165
	20:00	3	61	26	10	4	1	2	8	0	0	1	2	3	121
	21:00	1	91	28	18	1	1	1	11	1	2	1	0	5	161
	22:00	0	45	31	17	1	0	0	8	0	0	1	0	0	103
	23:00	1	34	23	14	3	1	0	6	0	0	1	0	0	83
Daily Total :		26	1038	428	309	44	22	9	128	7	5	8	5	26	2055
Percent :		1%	51%	21%	15%	2%	1%	0%	6%	0%	0%	0%	0%	1%	
Average :		1	43	18	13	2	1	0	5	0	0	0	0	1	84

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/12/18	00:00	0	67	16	10	2	1	1	7	0	3	2	0	2	111
Sun	01:00	0	48	20	5	2	1	0	1	0	0	0	0	0	77
	02:00	0	10	10	3	0	0	0	2	0	0	0	0	0	25
	03:00	0	13	9	2	2	0	0	1	0	0	0	0	0	27
	04:00	0	24	14	5	2	0	0	3	0	0	0	0	0	48
	05:00	0	32	33	10	1	0	0	1	0	0	1	0	0	78
	06:00	0	52	28	10	3	1	2	10	0	0	0	0	0	106
	07:00	0	53	22	11	2	0	0	3	0	0	1	0	0	92
	08:00	1	65	21	12	5	1	0	7	0	0	0	0	1	113
	09:00	3	58	20	17	1	1	0	4	0	0	1	0	0	105
	10:00	1	35	25	19	0	0	0	8	0	1	0	0	0	89
	11:00	4	40	20	17	1	0	0	5	0	0	0	0	1	88
	12:00	1	34	21	18	3	0	0	11	0	0	0	0	0	88
	13:00	1	52	21	20	3	1	1	4	1	0	1	0	0	105
	14:00	2	68	23	16	3	3	0	13	1	0	0	1	0	130
	15:00	1	77	33	16	3	3	0	13	0	1	1	0	0	148
	16:00	1	72	32	25	2	2	0	14	0	0	0	0	1	149
	17:00	0	73	25	20	1	3	3	7	1	0	3	0	2	138
	18:00	3	70	18	23	4	0	1	10	0	1	2	0	3	135
	19:00	4	68	19	21	6	1	0	23	0	5	0	2	5	154
	20:00	1	113	18	16	1	1	0	15	2	1	2	0	6	176
	21:00	3	49	19	17	6	2	0	11	0	0	2	0	1	110
	22:00	1	59	26	15	2	0	0	13	0	0	0	0	1	117
	23:00	2	41	17	10	5	1	0	7	0	1	1	0	1	86
Daily Total :		29	1273	510	338	60	22	8	193	5	13	17	3	24	2495
Percent :		1%	51%	20%	14%	2%	1%	0%	8%	0%	1%	1%	0%	1%	
Average :		1	53	21	14	3	1	0	8	0	1	1	0	1	104

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/13/18	00:00	2	50	18	6	1	1	0	12	0	0	1	0	2	93
Mon	01:00	1	61	13	3	3	2	0	6	0	0	1	1	0	91
	02:00	0	42	9	4	2	0	0	3	0	0	0	0	0	60
	03:00	1	22	11	2	2	0	1	2	0	0	1	0	0	42
	04:00	0	19	13	6	3	0	1	5	0	0	0	0	0	47
	05:00	0	26	33	7	2	0	0	6	0	0	0	0	0	74
	06:00	1	52	24	17	3	0	0	5	1	0	0	0	0	103
	07:00	0	51	25	16	5	2	0	4	0	1	0	0	0	104
	08:00	1	61	20	18	3	3	0	6	0	0	1	0	1	114
	09:00	4	60	18	14	1	3	1	7	0	0	1	1	1	111
	10:00	1	51	24	18	3	2	0	6	0	0	0	0	0	105
	11:00	2	55	15	18	3	1	0	7	1	0	0	1	0	103
	12:00	1	52	23	20	3	1	0	6	0	0	2	0	0	108
	13:00	2	49	26	22	3	2	0	12	2	0	0	1	1	120
	14:00	2	59	23	20	3	1	0	6	0	0	2	2	2	120
	15:00	2	59	17	21	3	0	0	6	0	0	0	0	5	113
	16:00	2	69	19	23	3	2	0	7	0	1	2	0	1	129
	17:00	2	58	20	17	4	1	1	6	1	0	1	0	0	111
	18:00	1	58	25	18	3	4	0	6	1	0	2	1	3	122
	19:00	2	88	17	24	2	1	0	16	0	0	2	1	2	155
	20:00	3	76	26	16	9	5	1	6	0	0	4	0	2	148
	21:00	4	46	23	18	3	3	1	9	0	0	1	1	0	109
	22:00	1	46	20	14	4	3	0	10	0	0	1	0	0	99
	23:00	2	61	22	7	1	2	0	7	1	0	2	0	0	105
Daily Total :		37	1271	484	349	72	39	6	166	7	2	24	9	20	2486
Percent :		1%	51%	19%	14%	3%	2%	0%	7%	0%	0%	1%	0%	1%	
Average :		2	53	20	15	3	2	0	7	0	0	1	0	1	104

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/14/18	00:00	0	46	10	7	1	1	0	9	1	1	1	0	1	78
Tue	01:00	0	39	13	4	0	0	0	8	1	0	0	0	0	65
	02:00	0	30	10	1	2	0	0	3	0	0	0	0	0	46
	03:00	0	18	16	0	2	0	0	4	0	0	0	0	0	40
	04:00	0	16	17	1	3	1	1	1	0	0	0	0	0	40
	05:00	1	31	26	4	0	1	0	8	0	0	1	0	0	72
	06:00	0	57	25	8	7	2	0	9	0	0	1	0	1	110
	07:00	2	41	25	17	2	1	0	3	0	0	2	0	1	94
	08:00	0	44	20	15	3	1	0	7	1	0	0	0	2	93
	09:00	0	27	14	8	0	1	0	1	0	0	0	0	0	51
	10:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	18:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	20:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	21:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	22:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		3	349	176	65	20	8	1	53	3	1	5	0	5	689
Percent :		0%	51%	26%	9%	3%	1%	0%	8%	0%	0%	1%	0%	1%	
Average :		0	15	7	3	1	0	0	2	0	0	0	0	0	28

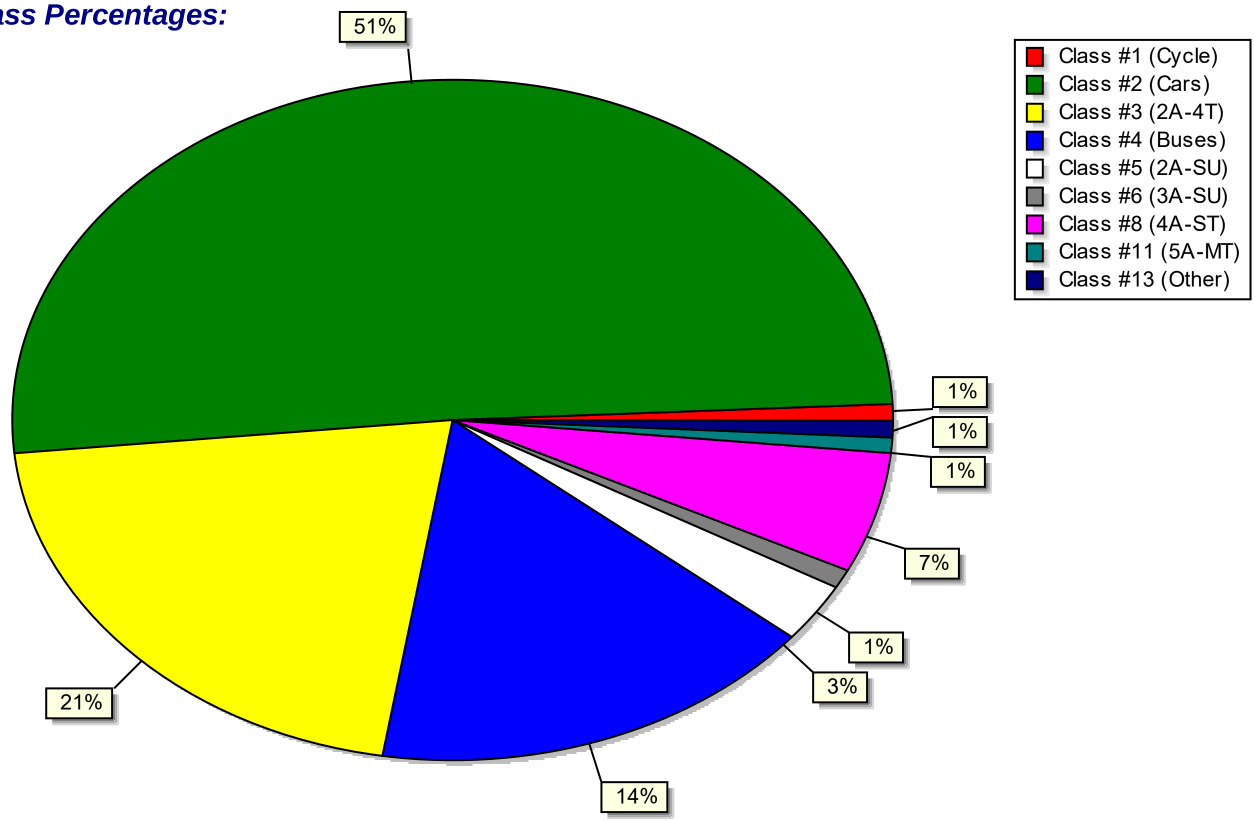
(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/15/18	00:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wed	01:00	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		0	1	0	0	0	0	0	0	0	0	0	0	0	1
Percent :		0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		0	0	0	0	0	0	0	0	0	0	0	0	0	0

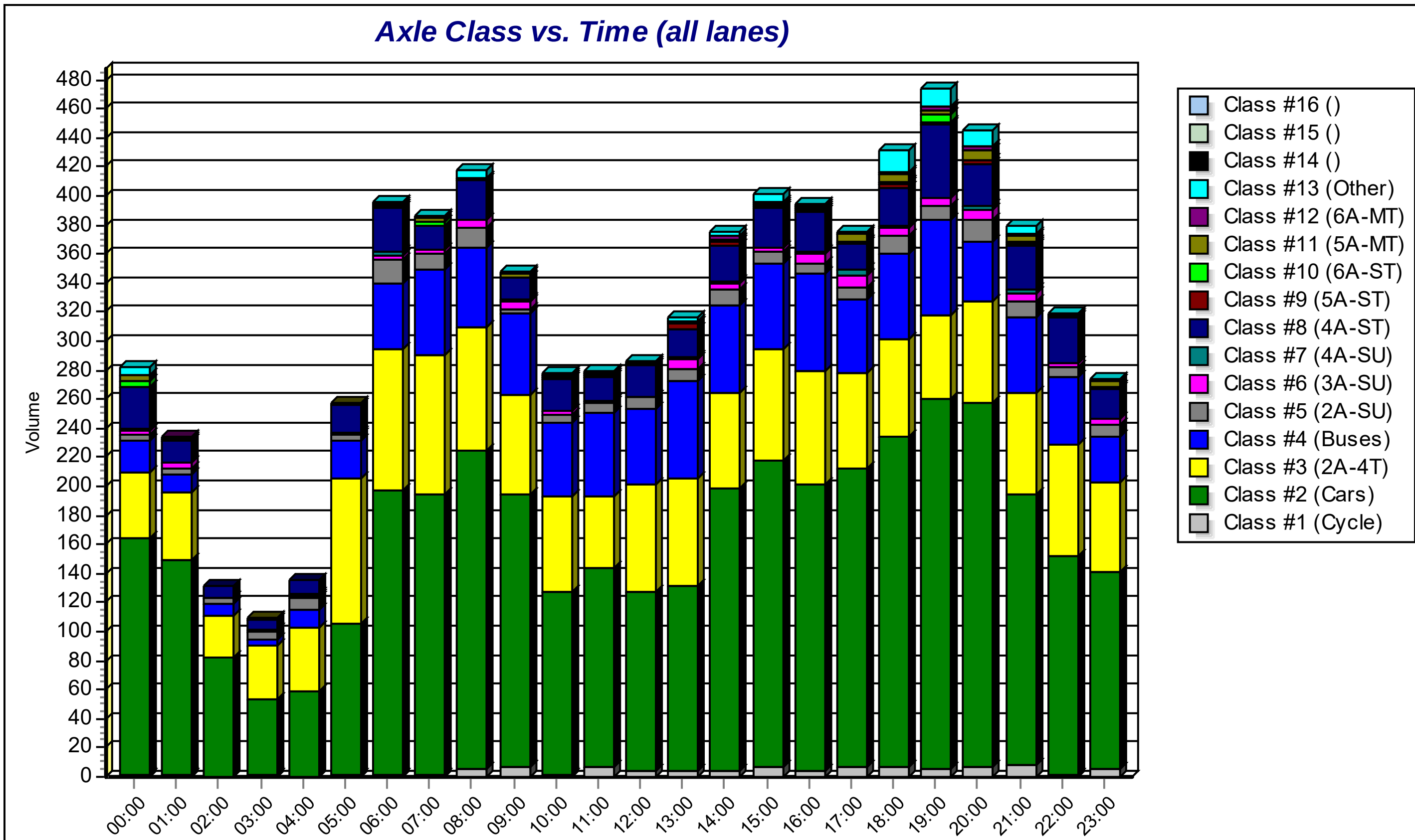
Basic Axle Class Summary: 236_046_VHB_ATR 9

(DEFAULTC) Description	Lane	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
TOTAL COUNT :	#1.	95	3932	1598	1061	196	91	24	540	22	21	54	17	75	7726
		95	3932	1598	1061	196	91	24	540	22	21	54	17	75	7726
Percents :	#1.	1%	51%	21%	14%	3%	1%	0%	7%	0%	0%	1%	0%	1%	100%
		1%	51%	21%	14%	3%	1%	0%	7%	0%	0%	1%	0%	1%	
Average :	#1.	1	39	16	11	2	1	0	5	0	0	1	0	1	77
		1	39	16	11	2	1	0	5	0	0	1	0	1	77
Days & ADT :	#1.	4.2	1835												
		4.2	1835												

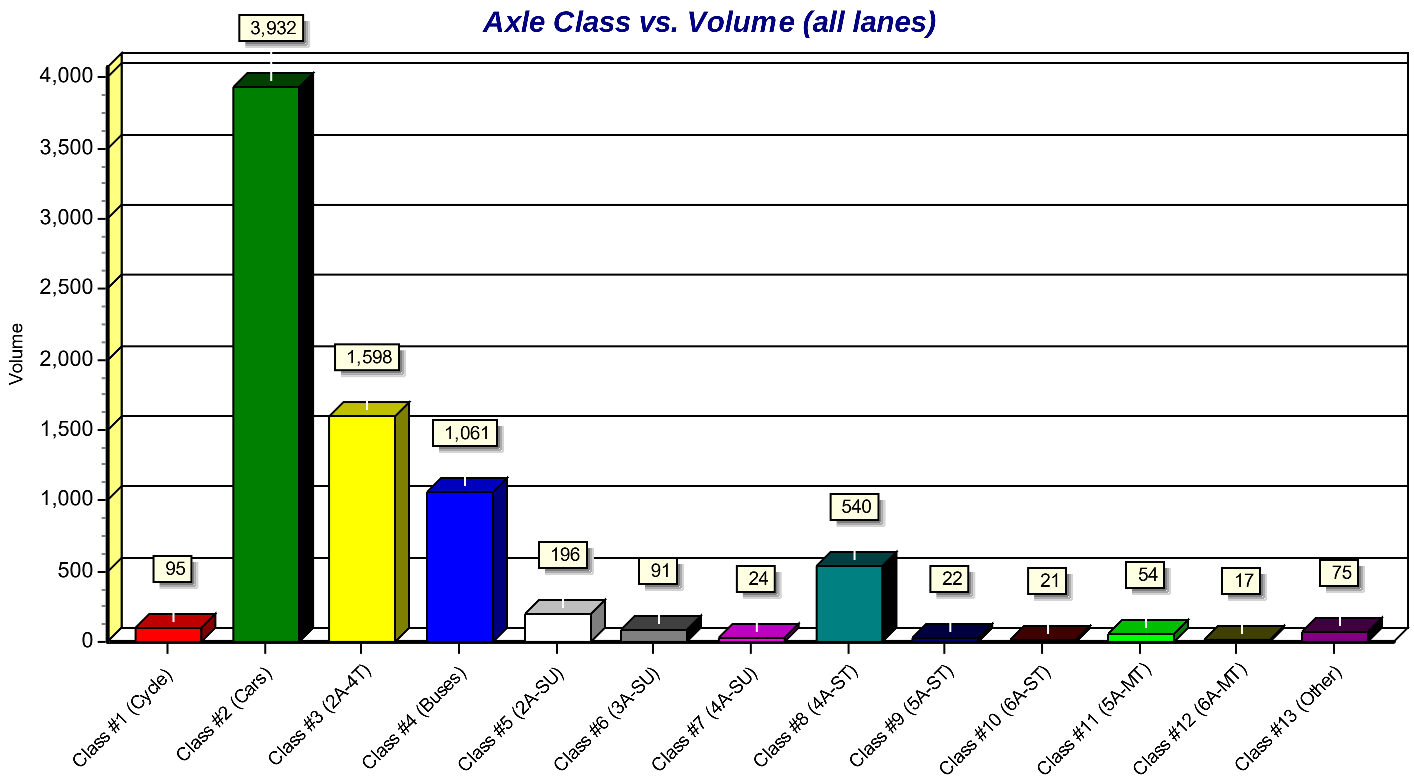
236_046_VHB_ATR 9 Axle Class Charts For Data From: 22:00 - 08/10/2018 To: 02:59 - 08/15/2018

Axle Class Percentages:





236_046_VHB_ATR 9 Axle Class Charts For Data From: 22:00 - 08/10/2018 To: 02:59 - 08/15/2018



Basic Speed Classification Report: 236_046_VHB_ATR

Lane #1 Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length	Comment
1.	W	West	Ax-Ax	3.0 ft	6.0 ft	

Lane #1 Basic Speed Classification Data From: 22:00 - 08/10/2018 To: 02:59 - 08/15/2018

(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
Date	Time	0.0 - 19.9	20.0 - 24.9	25.0 - 29.9	30.0 - 34.9	35.0 - 39.9	40.0 - 44.9	45.0 - 49.9	50.0 - 54.9	55.0 - 59.9	60.0 - 64.9	65.0 - 69.9	70.0 - 74.9	75.0 - 79.9	80.0 - 84.9	85.0 - 89.9	Other	Total
08/10/18	22:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fri	23:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Percent :		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Average :		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77

Speeds - Average: 0.0 50% : 0.0 67% : 0.0 85% : 0.0 10mph Pace: 0.0 - 9.9 (0.0%)

(DEFAULTX) Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
08/11/18	00:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sat	01:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	03:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	04:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	05:00	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34
	06:00	69	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	77
	07:00	90	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96
	08:00	94	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98
	09:00	76	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	81
	10:00	78	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84
	11:00	85	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88
	12:00	81	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90
	13:00	86	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	91
	14:00	119	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	125
	15:00	131	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	140
	16:00	108	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	117
	17:00	122	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	127
	18:00	156	17	0	0	0	0	0	0	0	0	1	0	0	0	0	0	174
	19:00	142	22	1	0	0	0	0	0	0	0	0	0	0	0	0	0	165
	20:00	117	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121
	21:00	150	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	161
	22:00	97	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	103
	23:00	77	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	83
Daily Total :		1912	135	7	0	0	0	0	0	0	0	1	0	0	0	0	0	2055
Percent :		93%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		80	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Speeds - Average: 10.9 50% : 10.8 67% : 14.4 85% : 18.3 10mph Pace: 9.6 - 19.5 (47.0%)

Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
(DEFAULTX)																		
08/12/18	00:00	106	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	111
Sun	01:00	71	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	77
	02:00	21	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
	03:00	18	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	27
	04:00	41	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	48
	05:00	66	11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	78
	06:00	102	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	106
	07:00	91	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92
	08:00	109	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113
	09:00	99	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105
	10:00	76	11	2	0	0	0	0	0	0	0	0	0	0	0	0	0	89
	11:00	82	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88
	12:00	78	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	88
	13:00	90	14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	105
	14:00	116	11	3	0	0	0	0	0	0	0	0	0	0	0	0	0	130
	15:00	147	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	148
	16:00	140	8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	149
	17:00	132	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	138
	18:00	133	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	135
	19:00	152	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	154
	20:00	166	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	176
	21:00	109	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	110
	22:00	115	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	117
	23:00	84	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	86
Daily Total :		2344	132	18	1	0	0	0	0	0	0	0	0	0	0	0	0	2495
Percent :		94%	5%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		98	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	86

Speeds - Average: 10.7 50% : 10.6 67% : 14.0 85% : 18.0 10mph Pace: 7.0 - 16.9 (49.1%)

Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
(DEFAULTX)																		
08/13/18	00:00	91	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93
Mon	01:00	84	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	91
	02:00	56	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	60
	03:00	37	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	42
	04:00	42	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	47
	05:00	62	9	3	0	0	0	0	0	0	0	0	0	0	0	0	0	74
	06:00	101	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	103
	07:00	102	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104
	08:00	113	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	114
	09:00	108	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	111
	10:00	97	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	105
	11:00	95	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	103
	12:00	103	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	108
	13:00	114	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120
	14:00	118	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120
	15:00	107	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	113
	16:00	125	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	129
	17:00	108	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	111
	18:00	121	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	122
	19:00	155	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	155
	20:00	147	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	148
	21:00	105	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	109
	22:00	92	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	99
	23:00	98	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105
Daily Total :		2381	86	16	2	0	0	1	0	0	0	0	0	0	0	0	0	2486
Percent :		96%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		99	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	105

Speeds - Average: 10.6 50% : 10.5 67% : 13.7 85% : 17.6 10mph Pace: 5.9 - 15.8 (50.7%)

(DEFAULTX) Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
08/14/18	00:00	76	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	78
Tue	01:00	59	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	65
	02:00	40	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	46
	03:00	32	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	40
	04:00	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
	05:00	68	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	72
	06:00	103	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	110
	07:00	92	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	94
	08:00	88	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93
	09:00	50	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51
	10:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	18:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	20:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	21:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	22:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		648	33	8	0	0	0	0	0	0	0	0	0	0	0	0	0	689
Percent :		94%	5%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		27	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104

Speeds - Average: 10.7 50% : 10.6 67% : 14.2 85% : 18.1 10mph Pace: 9.9 - 19.8 (47.6%)

(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
Date	Time	0.0 - 19.9	20.0 - 24.9	25.0 - 29.9	30.0 - 34.9	35.0 - 39.9	40.0 - 44.9	45.0 - 49.9	50.0 - 54.9	55.0 - 59.9	60.0 - 64.9	65.0 - 69.9	70.0 - 74.9	75.0 - 79.9	80.0 - 84.9	85.0 - 89.9	Other	Total
08/15/18	00:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wed	01:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Percent :		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	
Average :		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28

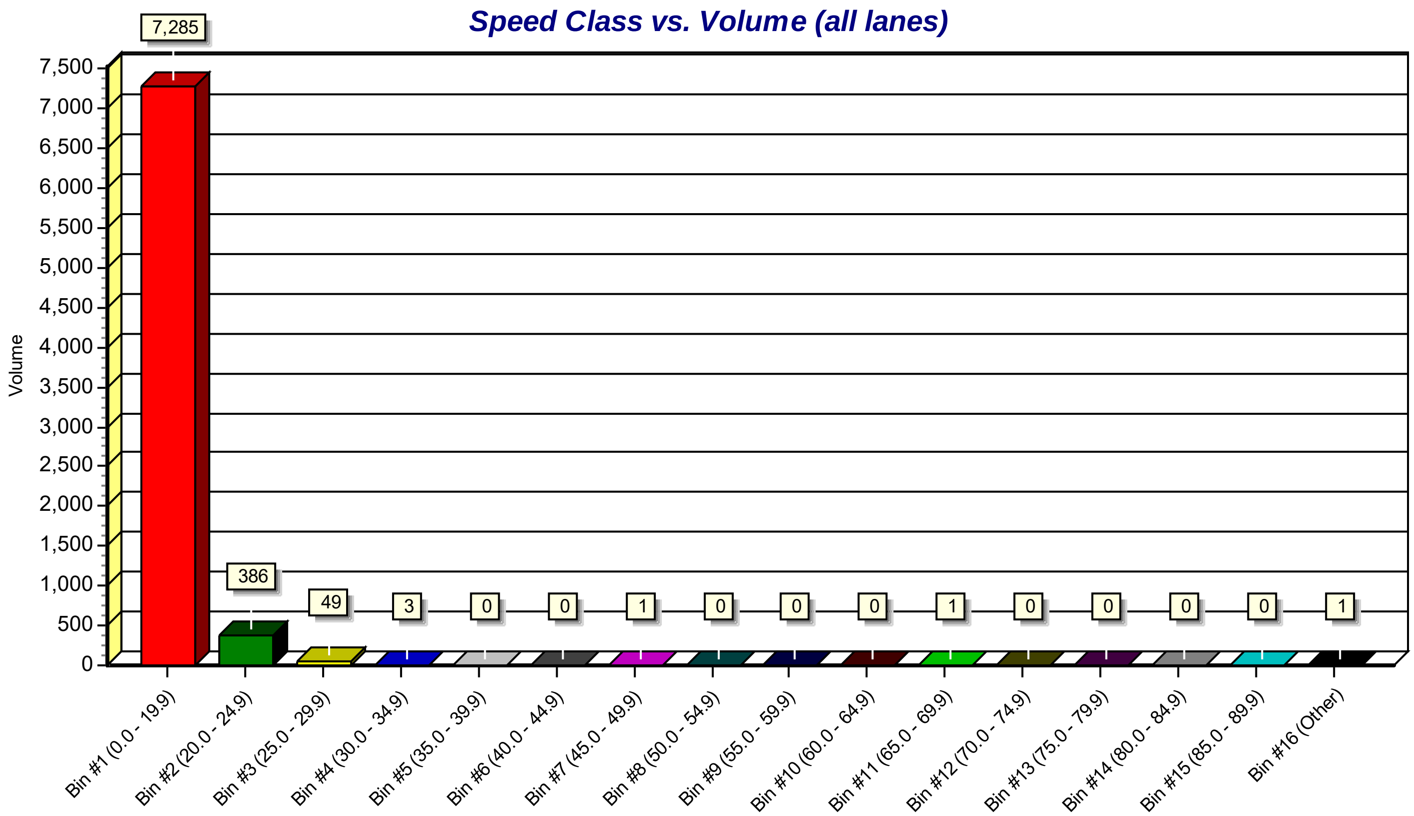
Speeds - Average: 0.0 50% : 0.0 67% : 0.0 85% : 0.0 10mph Pace: 176.4 -186.3 (0.0%)

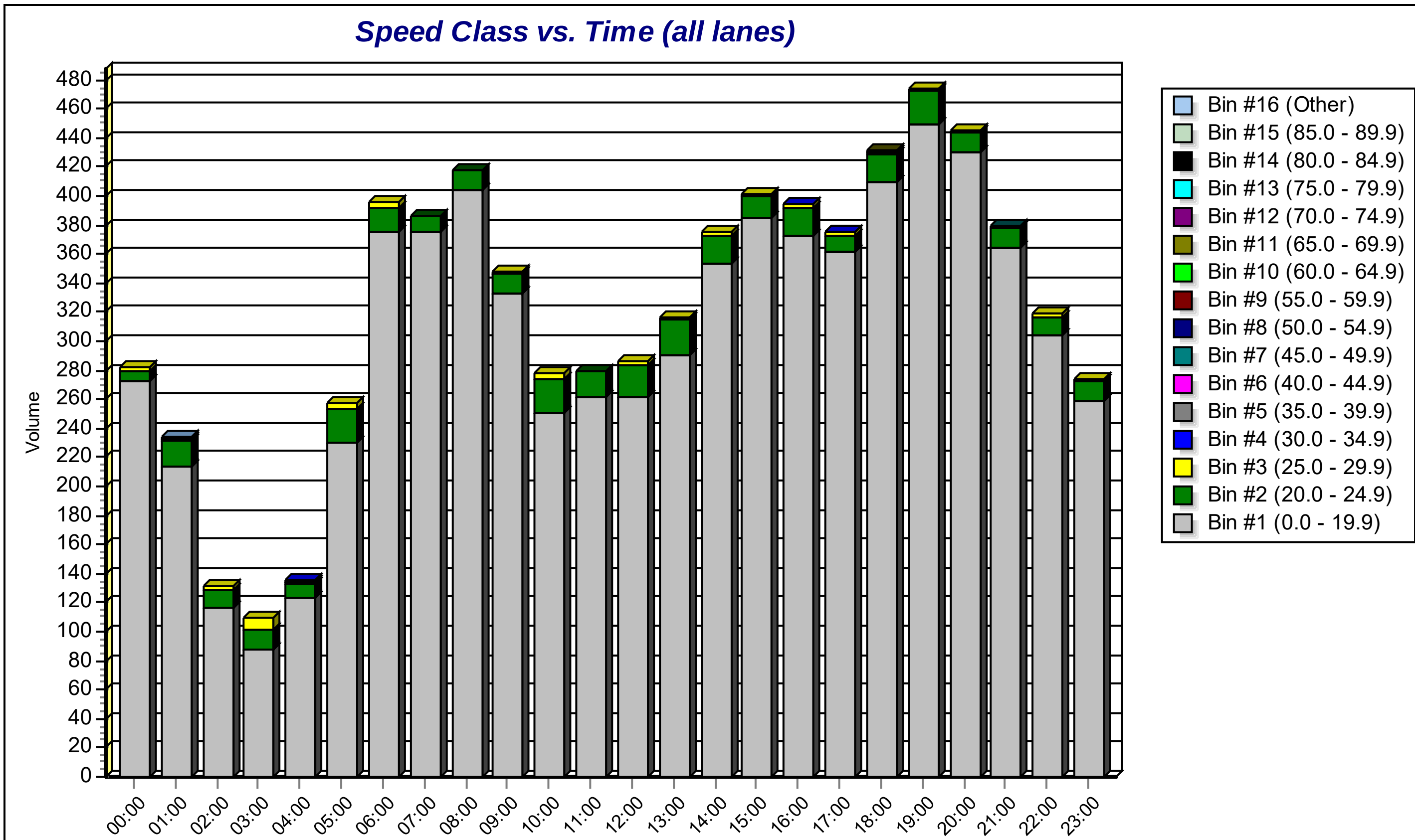
Basic Speed Class Summary: 236_046_VHB_ATR 9

(DEFAULTX)

Description	Lane	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
TOTAL COUNT :	#1.	7285	386	49	3	0	0	1	0	0	0	1	0	0	0	0	1	7726
		7285	386	49	3	0	0	1	0	0	0	1	0	0	0	0	1	7726
Percents :	#1.	94%	5%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
		94%	5%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :	#1.	72	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76
		72	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76
Days & ADT :	#1.	4.2	1835															
		4.2	1835															
Avg,50,67,85%:	#1.	10.7	10.7	14.2	18.0	7.0	- 16.9	48%										
		10.7	10.7	14.2	18.0	7.0	- 16.9	48%										

236_046_VHB_ATR 9 Speed Class Charts For Data From: 22:00 - 08/10/2018 To: 02:59 - 08/15/2018





Basic Volume Report: 236_046_VHB_ATR 9

Station ID : 236_046_VHB_ATR 9
Info Line 1 : C-E Conn Roadway, before Badge
Info Line 2 : Logan Airport
GPS Lat/Lon :
DB File : 236046VHBATR 9.DB

Last Connected Device Type : RoadRunner3
Version Number : 1.32
Serial Number : 17748
Number of Lanes : 1
Posted Speed Limit : 0.0 mph

Lane #1 Configuration

#	Dir.	Information	Volume Mode	Volume Sensors	Divide By 2	Comment
1.	W	West	Normal	Veh.	No	

Lane #1 Basic Volume Data From: 21:15 - 08/10/2018 To: 03:14 - 08/15/2018

Date	Time	:00	:15	:30	:45	Total
08/10/18	21:00		0	0	0	0
Fri	22:00	0	0	0	0	0
	23:00	0	0	0	0	0
Day Total :						0

AM Total :		Peak AM Hour :	Peak AM Factor :	Average Period :	0.0
PM Total :	0 (0.0%)	Peak PM Hour :	Peak PM Factor :	Average Hour :	0.0

Date	Time	:00	:15	:30	:45	Total
08/11/18	00:00	0	0	0	0	0
Sat	01:00	0	0	0	0	0
	02:00	0	0	0	0	0
	03:00	0	0	0	0	0
	04:00	0	0	0	0	0
	05:00	0	0	9	25	34
	06:00	17	15	27	18	77
	07:00	20	30	24	22	96
	08:00	24	22	26	26	98
	09:00	21	31	16	13	81
	10:00	23	19	25	17	84
	11:00	21	32	16	19	88
	12:00	19	22	24	25	90
	13:00	25	20	23	23	91
	14:00	25	37	29	34	125
	15:00	44	35	34	27	140
	16:00	28	37	25	27	117
	17:00	36	31	26	34	127
	18:00	35	33	53	53	174
	19:00	40	39	43	43	165
	20:00	28	31	31	31	121
	21:00	44	46	43	28	161
	22:00	24	24	20	35	103
	23:00	29	22	18	14	83
Day Total :						2055

AM Total :	558 (27.2%)	Peak AM Hour : 08:30 =	104 (5.1%)	Peak AM Factor : 0.812		Average Period :	21.4
PM Total :	1497 (72.8%)	Peak PM Hour : 18:30 =	185 (9.0%)	Peak PM Factor : 0.873		Average Hour :	85.6

Date	Time	:00	:15	:30	:45	Total
08/12/18	00:00	18	47	19	27	111
Sun	01:00	31	23	12	11	77
	02:00	9	4	6	6	25
	03:00	3	9	8	7	27
	04:00	11	11	8	18	48
	05:00	12	24	11	31	78
	06:00	34	30	24	18	106
	07:00	22	21	21	28	92
	08:00	26	29	25	33	113
	09:00	18	34	23	30	105
	10:00	19	18	32	20	89
	11:00	19	27	22	20	88
	12:00	19	21	26	22	88
	13:00	17	30	29	29	105
	14:00	33	21	39	37	130
	15:00	36	42	29	41	148
	16:00	38	33	37	41	149
	17:00	33	41	30	34	138
	18:00	27	38	35	35	135
	19:00	33	29	56	36	154
	20:00	45	54	43	34	176
	21:00	30	23	30	27	110
	22:00	39	23	27	28	117
	23:00	23	24	18	21	86
Day Total :						2495

AM Total :	959 (38.4%)	Peak AM Hour : 00:15 =	124 (5.0%)	Peak AM Factor :	0.660	Average Period :	26.0
PM Total :	1536 (61.6%)	Peak PM Hour : 19:30 =	191 (7.7%)	Peak PM Factor :	0.853	Average Hour :	104.0

Date	Time	:00	:15	:30	:45	Total
08/13/18	00:00	26	24	18	25	93
Mon	01:00	24	19	22	26	91
	02:00	21	10	16	13	60
	03:00	7	9	10	16	42
	04:00	13	8	10	16	47
	05:00	12	24	15	23	74
	06:00	26	27	31	19	103
	07:00	27	22	27	28	104
	08:00	31	25	25	33	114
	09:00	28	28	26	29	111
	10:00	35	22	28	20	105
	11:00	31	27	22	23	103
	12:00	33	21	27	27	108
	13:00	28	34	36	22	120
	14:00	26	35	28	31	120
	15:00	31	25	29	28	113
	16:00	33	38	30	28	129
	17:00	30	37	23	21	111
	18:00	24	35	32	31	122
	19:00	35	41	37	42	155
	20:00	29	37	45	37	148
	21:00	25	32	30	22	109
	22:00	23	21	24	31	99
	23:00	33	23	26	23	105
Day Total :						2486

AM Total :	1047 (42.1%)	Peak AM Hour : 09:15 =	118 (4.7%)	Peak AM Factor : 0.843	Average Period : 25.9
PM Total :	1439 (57.9%)	Peak PM Hour : 19:00 =	155 (6.2%)	Peak PM Factor : 0.861	Average Hour : 103.6

Date	Time	:00	:15	:30	:45	Total
08/14/18	00:00	20	23	18	17	78
Tue	01:00	17	20	15	13	65
	02:00	16	12	6	12	46
	03:00	13	8	8	11	40
	04:00	6	11	12	11	40
	05:00	13	26	18	15	72
	06:00	25	25	27	33	110
	07:00	22	25	22	25	94
	08:00	24	15	21	33	93
	09:00	35	16	0	0	51
	10:00	0	0	0	0	0
	11:00	0	0	0	0	0
	12:00	0	0	0	0	0
	13:00	0	0	0	0	0
	14:00	0	0	0	0	0
	15:00	0	0	0	0	0
	16:00	0	0	0	0	0
	17:00	0	0	0	0	0
	18:00	0	0	0	0	0
	19:00	0	0	0	0	0
	20:00	0	0	0	0	0
	21:00	0	0	0	0	0
	22:00	0	0	0	0	0
	23:00	0	0	0	0	0
Day Total :						689

AM Total :	689 (100.0%)	Peak AM Hour : 06:00 =	110 (16.0%)	Peak AM Factor :	0.786	Average Period :	7.2
PM Total :	0 (0.0%)	Peak PM Hour :		Peak PM Factor :		Average Hour :	28.7

Date	Time	:00	:15	:30	:45	Total
08/15/18	00:00	0	0	0	0	0
Wed	01:00	1	0	0	0	1
	02:00	0	0	0	0	0
Day Total :						1

AM Total :	1 (100.0%)	Peak AM Hour : 00:15 =	1 (100.0%)	Peak AM Factor : 0.250		Average Period :	0.1
PM Total :		Peak PM Hour :		Peak PM Factor :		Average Hour :	0.3

Basic Volume Summary: 236_046_VHB_ATR 9

Grand Total For Data From: 21:15 - 08/10/2018 To: 03:14 - 08/15/2018

Lane	Total Count		# Of Days	ADT	Avg. Period	Avg. Hour	AM Total & Percent	PM Total & Percent
#1.	7726	(100.0%)	4.24	1822	19.0	75.9	3254 (42.1%)	4472 (57.9%)
ALL	7726		4.24	1822	19.0	75.9	3254 (42.1%)	4472 (57.9%)

Lane	Peak AM Hour		Date	Peak AM Factor	Peak PM Hour		Date	Peak PM Factor
#1.	00:15 =	124	08/12/2018	0.660	19:30 =	191	08/12/2018	0.853

Basic Volume Report: 236_046_VHB_ATR 10

Station ID : 236_046_VHB_ATR 10
Info Line 1 : Terminal E Arrival Curb 1 Exit
Info Line 2 : Logan Airport
GPS Lat/Lon :
DB File : 236046VHBATR 10.DB

Last Connected Device Type : RoadRunner3
Version Number : 1.32
Serial Number : 17752
Number of Lanes : 1
Posted Speed Limit : 0.0 mph

Lane #1 Configuration

#	Dir.	Information	Volume Mode	Volume Sensors	Divide By 2	Comment
1.	W	West	Normal	Veh.	No	

Lane #1 Basic Volume Data From: 23:00 - 08/10/2018 To: 01:14 - 08/15/2018

Date	Time	:00	:15	:30	:45	Total
08/10/18	23:00	0	0	0	0	0
Day Total :						0

AM Total :		Peak AM Hour :		Peak AM Factor :	Average Period :	0.0
PM Total :	0 (0.0%)	Peak PM Hour :		Peak PM Factor :	Average Hour :	0.0

Date	Time	:00	:15	:30	:45	Total
08/11/18	00:00	0	0	0	0	0
Sat	01:00	0	0	0	0	0
	02:00	0	0	0	0	0
	03:00	0	0	0	0	0
	04:00	0	6	10	7	23
	05:00	9	11	5	12	37
	06:00	12	12	18	13	55
	07:00	12	16	13	14	55
	08:00	17	19	13	9	58
	09:00	17	13	15	13	58
	10:00	18	18	15	18	69
	11:00	16	19	14	17	66
	12:00	19	17	17	27	80
	13:00	33	22	25	22	102
	14:00	23	31	44	29	127
	15:00	48	44	44	36	172
	16:00	45	59	31	24	159
	17:00	29	24	25	24	102
	18:00	35	37	61	58	191
	19:00	74	54	46	54	228
	20:00	38	46	25	59	168
	21:00	75	55	47	59	236
	22:00	40	49	27	28	144
	23:00	19	20	14	10	63
Day Total :						2193

AM Total :	421 (19.2%)	Peak AM Hour : 10:00 =	69 (3.1%)	Peak AM Factor : 0.908	Average Period :	22.8
PM Total :	1772 (80.8%)	Peak PM Hour : 18:30 =	247 (11.3%)	Peak PM Factor : 0.823	Average Hour :	91.4

Date	Time	:00	:15	:30	:45	Total
08/12/18	00:00	13	15	10	20	58
Sun	01:00	18	11	6	6	41
	02:00	9	5	4	5	23
	03:00	4	5	6	7	22
	04:00	10	8	7	8	33
	05:00	8	17	10	22	57
	06:00	14	27	23	11	75
	07:00	14	21	13	15	63
	08:00	9	19	10	17	55
	09:00	17	17	15	22	71
	10:00	17	11	14	13	55
	11:00	20	27	11	15	73
	12:00	12	13	14	22	61
	13:00	27	31	22	44	124
	14:00	44	26	52	60	182
	15:00	52	58	70	72	252
	16:00	56	48	52	31	187
	17:00	24	32	25	25	106
	18:00	21	33	36	43	133
	19:00	48	73	60	41	222
	20:00	65	64	63	37	229
	21:00	40	43	31	37	151
	22:00	40	28	35	58	161
	23:00	53	35	31	32	151
Day Total :						2585

AM Total :	626 (24.2%)	Peak AM Hour : 05:45 =	86 (3.3%)	Peak AM Factor :	0.796	Average Period :	26.9
PM Total :	1959 (75.8%)	Peak PM Hour : 15:15 =	256 (9.9%)	Peak PM Factor :	0.877	Average Hour :	107.7

Date	Time	:00	:15	:30	:45	Total
08/13/18	00:00	13	19	7	13	52
Mon	01:00	6	9	4	12	31
	02:00	1	10	5	10	26
	03:00	3	7	4	7	21
	04:00	7	11	11	10	39
	05:00	11	11	14	12	48
	06:00	11	16	19	17	63
	07:00	19	20	16	19	74
	08:00	16	19	18	17	70
	09:00	26	26	24	22	98
	10:00	18	24	17	15	74
	11:00	26	20	22	16	84
	12:00	26	29	19	28	102
	13:00	33	34	30	25	122
	14:00	33	43	46	44	166
	15:00	34	30	41	47	152
	16:00	42	52	68	47	209
	17:00	26	38	30	36	130
	18:00	21	32	39	48	140
	19:00	40	55	61	81	237
	20:00	69	64	50	50	233
	21:00	56	38	30	26	150
	22:00	27	32	33	40	132
	23:00	43	34	31	19	127
Day Total :						2580

AM Total :	680 (26.4%)	Peak AM Hour : 09:00 =	98 (3.8%)	Peak AM Factor :	0.942	Average Period :	26.9
PM Total :	1900 (73.6%)	Peak PM Hour : 19:30 =	275 (10.7%)	Peak PM Factor :	0.849	Average Hour :	107.5

Date	Time	:00	:15	:30	:45	Total
08/14/18	00:00	9	23	6	11	49
Tue	01:00	21	16	16	14	67
	02:00	10	12	5	9	36
	03:00	4	8	6	7	25
	04:00	6	6	8	11	31
	05:00	9	13	10	15	47
	06:00	12	20	15	25	72
	07:00	16	18	17	14	65
	08:00	17	15	17	20	69
	09:00	21	24	28	21	94
	10:00	16	16	26	15	73
	11:00	24	17	18	26	85
	12:00	24	23	26	34	107
	13:00	25	23	33	28	109
	14:00	22	41	29	36	128
	15:00	31	43	59	36	169
	16:00	38	57	33	34	162
	17:00	21	24	26	26	97
	18:00	17	34	34	37	122
	19:00	37	66	35	33	171
	20:00	36	44	68	73	221
	21:00	47	28	29	24	128
	22:00	15	31	26	26	98
	23:00	37	22	19	13	91
Day Total :						2316

AM Total :	713 (30.8%)	Peak AM Hour : 09:00 =	94 (4.1%)	Peak AM Factor :	0.839	Average Period :	24.1
PM Total :	1603 (69.2%)	Peak PM Hour : 20:15 =	232 (10.0%)	Peak PM Factor :	0.795	Average Hour :	96.5

Date	Time	:00	:15	:30	:45	Total
08/15/18	00:00	10	11	16	11	48
Wed	01:00	9				9
Day Total :						57

AM Total :	57 (100.0%)	Peak AM Hour : 00:00 =	48 (84.2%)	Peak AM Factor : 0.750		Average Period :	11.4
PM Total :		Peak PM Hour :		Peak PM Factor :		Average Hour :	45.6

Basic Volume Summary: 236_046_VHB_ATR 10

Grand Total For Data From: 23:00 - 08/10/2018 To: 01:14 - 08/15/2018

Lane	*Total Count*		*# Of Days*	*ADT*	*Avg. Period*	*Avg. Hour*	*AM Total & Percent*	*PM Total & Percent*
#1.	9731	(100.0%)	4.09	2377	24.8	99.0	2497 (25.7%)	7234 (74.3%)
ALL	9731		4.09	2377	24.8	99.0	2497 (25.7%)	7234 (74.3%)

Lane	*Peak AM Hour*		*Date*	*Peak AM Factor*	*Peak PM Hour*		*Date*	*Peak PM Factor*
#1.	09:00 =	98	08/13/2018	0.942	19:30 =	275	08/13/2018	0.849

Basic Volume Report: 236_046_VHB_ATR 10

Station ID : 236_046_VHB_ATR 10
Info Line 1 : Terminal E Arrival Curb 1 Exit
Info Line 2 : Logan Airport
GPS Lat/Lon :
DB File : 236046VHBATR 10.DB

Last Connected Device Type : RoadRunner3
Version Number : 1.32
Serial Number : 17752
Number of Lanes : 1
Posted Speed Limit : 0.0 mph

Lane #1 Configuration

#	Dir.	Information	Volume Mode	Volume Sensors	Divide By 2	Comment
1.	W	West	Normal	Veh.	No	

Lane #1 Basic Volume Data From: 23:00 - 08/10/2018 To: 01:14 - 08/15/2018

Date	Time	:00	:15	:30	:45	Total
08/10/18	23:00	0	0	0	0	0
Day Total :						0

AM Total :		Peak AM Hour :		Peak AM Factor :		Average Period :	0.0
PM Total :	0 (0.0%)	Peak PM Hour :		Peak PM Factor :		Average Hour :	0.0

Date	Time	:00	:15	:30	:45	Total
08/11/18	00:00	0	0	0	0	0
Sat	01:00	0	0	0	0	0
	02:00	0	0	0	0	0
	03:00	0	0	0	0	0
	04:00	0	6	10	7	23
	05:00	9	11	5	12	37
	06:00	12	12	18	13	55
	07:00	12	16	13	14	55
	08:00	17	19	13	9	58
	09:00	17	13	15	13	58
	10:00	18	18	15	18	69
	11:00	16	19	14	17	66
	12:00	19	17	17	27	80
	13:00	33	22	25	22	102
	14:00	23	31	44	29	127
	15:00	48	44	44	36	172
	16:00	45	59	31	24	159
	17:00	29	24	25	24	102
	18:00	35	37	61	58	191
	19:00	74	54	46	54	228
	20:00	38	46	25	59	168
	21:00	75	55	47	59	236
	22:00	40	49	27	28	144
	23:00	19	20	14	10	63
Day Total :						2193

AM Total :	421 (19.2%)	Peak AM Hour : 10:00 =	69 (3.1%)	Peak AM Factor : 0.908		Average Period :	22.8
PM Total :	1772 (80.8%)	Peak PM Hour : 18:30 =	247 (11.3%)	Peak PM Factor : 0.823		Average Hour :	91.4

Date	Time	:00	:15	:30	:45	Total
08/12/18	00:00	13	15	10	20	58
Sun	01:00	18	11	6	6	41
	02:00	9	5	4	5	23
	03:00	4	5	6	7	22
	04:00	10	8	7	8	33
	05:00	8	17	10	22	57
	06:00	14	27	23	11	75
	07:00	14	21	13	15	63
	08:00	9	19	10	17	55
	09:00	17	17	15	22	71
	10:00	17	11	14	13	55
	11:00	20	27	11	15	73
	12:00	12	13	14	22	61
	13:00	27	31	22	44	124
	14:00	44	26	52	60	182
	15:00	52	58	70	72	252
	16:00	56	48	52	31	187
	17:00	24	32	25	25	106
	18:00	21	33	36	43	133
	19:00	48	73	60	41	222
	20:00	65	64	63	37	229
	21:00	40	43	31	37	151
	22:00	40	28	35	58	161
	23:00	53	35	31	32	151
Day Total :						2585

AM Total :	626 (24.2%)	Peak AM Hour : 05:45 =	86 (3.3%)	Peak AM Factor :	0.796	Average Period :	26.9
PM Total :	1959 (75.8%)	Peak PM Hour : 15:15 =	256 (9.9%)	Peak PM Factor :	0.877	Average Hour :	107.7

Date	Time	:00	:15	:30	:45	Total
08/13/18	00:00	13	19	7	13	52
Mon	01:00	6	9	4	12	31
	02:00	1	10	5	10	26
	03:00	3	7	4	7	21
	04:00	7	11	11	10	39
	05:00	11	11	14	12	48
	06:00	11	16	19	17	63
	07:00	19	20	16	19	74
	08:00	16	19	18	17	70
	09:00	26	26	24	22	98
	10:00	18	24	17	15	74
	11:00	26	20	22	16	84
	12:00	26	29	19	28	102
	13:00	33	34	30	25	122
	14:00	33	43	46	44	166
	15:00	34	30	41	47	152
	16:00	42	52	68	47	209
	17:00	26	38	30	36	130
	18:00	21	32	39	48	140
	19:00	40	55	61	81	237
	20:00	69	64	50	50	233
	21:00	56	38	30	26	150
	22:00	27	32	33	40	132
	23:00	43	34	31	19	127
Day Total :						2580

AM Total :	680 (26.4%)	Peak AM Hour : 09:00 =	98 (3.8%)	Peak AM Factor :	0.942	Average Period :	26.9
PM Total :	1900 (73.6%)	Peak PM Hour : 19:30 =	275 (10.7%)	Peak PM Factor :	0.849	Average Hour :	107.5

Date	Time	:00	:15	:30	:45	Total
08/14/18	00:00	9	23	6	11	49
Tue	01:00	21	16	16	14	67
	02:00	10	12	5	9	36
	03:00	4	8	6	7	25
	04:00	6	6	8	11	31
	05:00	9	13	10	15	47
	06:00	12	20	15	25	72
	07:00	16	18	17	14	65
	08:00	17	15	17	20	69
	09:00	21	24	28	21	94
	10:00	16	16	26	15	73
	11:00	24	17	18	26	85
	12:00	24	23	26	34	107
	13:00	25	23	33	28	109
	14:00	22	41	29	36	128
	15:00	31	43	59	36	169
	16:00	38	57	33	34	162
	17:00	21	24	26	26	97
	18:00	17	34	34	37	122
	19:00	37	66	35	33	171
	20:00	36	44	68	73	221
	21:00	47	28	29	24	128
	22:00	15	31	26	26	98
	23:00	37	22	19	13	91
Day Total :						2316

AM Total :	713 (30.8%)	Peak AM Hour : 09:00 =	94 (4.1%)	Peak AM Factor : 0.839		Average Period :	24.1
PM Total :	1603 (69.2%)	Peak PM Hour : 20:15 =	232 (10.0%)	Peak PM Factor : 0.795		Average Hour :	96.5

Date	Time	:00	:15	:30	:45	Total
08/15/18	00:00	10	11	16	11	48
Wed	01:00	9				9
Day Total :						57

AM Total :	57 (100.0%)	Peak AM Hour : 00:00 =	48 (84.2%)	Peak AM Factor : 0.750		Average Period :	11.4
PM Total :		Peak PM Hour :		Peak PM Factor :		Average Hour :	45.6

Basic Volume Summary: 236_046_VHB_ATR 10

Grand Total For Data From: 23:00 - 08/10/2018 To: 01:14 - 08/15/2018

Lane	*Total Count*		*# Of Days*	*ADT*	*Avg. Period*	*Avg. Hour*	*AM Total & Percent*	*PM Total & Percent*
#1.	9731	(100.0%)	4.09	2377	24.8	99.0	2497 (25.7%)	7234 (74.3%)
ALL	9731		4.09	2377	24.8	99.0	2497 (25.7%)	7234 (74.3%)

Lane	*Peak AM Hour*		*Date*	*Peak AM Factor*	*Peak PM Hour*		*Date*	*Peak PM Factor*
#1.	09:00 =	98	08/13/2018	0.942	19:30 =	275	08/13/2018	0.849

Basic Axle Classification Report: 236_046_VHB_ATR

Station ID : 236_046_VHB_ATR 11
Info Line 1 : Terminal E Arrival Curb 2 Exit
Info Line 2 : Logan Airport
GPS Lat/Lon :
DB File : 236046VHBATR 11.DB

Last Connected Device Type : RoadRunner3
Version Number : 1.32
Serial Number : 17751
Number of Lanes : 1
Posted Speed Limit : 0.0 mph

Lane #1 Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length	Comment
1.	W	West	Ax-Ax	3.0 ft	6.0 ft	

Lane #1 Basic Axle Classification Data From: 23:00 - 08/10/2018 To: 02:59 - 08/15/2018

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/10/18	23:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Percent :		-	-	-	-	-	-	-	-	-	-	-	-	-	
Average :		0	0	0	0	0	0	0	0	0	0	0	0	0	0

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/11/18	00:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sat	01:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	03:00	0	8	4	0	0	0	0	0	0	0	0	0	0	12
	04:00	1	37	22	0	1	0	0	0	0	0	0	0	0	61
	05:00	2	86	37	0	5	0	1	0	0	0	0	0	0	131
	06:00	1	134	44	0	1	1	0	0	0	1	0	1	0	183
	07:00	3	106	28	0	5	1	0	1	0	0	0	0	0	144
	08:00	2	161	38	0	5	0	0	1	0	0	0	0	1	208
	09:00	0	131	33	0	4	1	0	1	0	0	1	0	0	171
	10:00	0	125	42	1	5	0	0	1	0	0	1	1	1	177
	11:00	1	104	33	2	1	1	0	1	0	0	0	0	0	143
	12:00	4	148	37	0	1	0	0	1	0	0	0	0	1	192
	13:00	0	203	53	2	1	0	1	4	0	1	0	1	1	267
	14:00	3	323	73	0	0	2	1	6	0	5	2	4	7	426
	15:00	0	429	64	0	1	2	4	4	0	2	1	15	16	538
	16:00	3	317	56	1	0	2	0	4	0	1	3	4	5	396
	17:00	2	308	59	1	0	1	1	4	1	3	0	8	7	395
	18:00	2	388	62	0	1	2	2	7	2	5	1	8	13	493
	19:00	0	341	60	0	0	3	1	8	1	12	5	10	29	470
	20:00	1	345	59	1	0	4	3	5	0	5	2	12	25	462
	21:00	4	311	69	0	0	2	6	3	2	6	3	16	35	457
	22:00	1	345	68	0	0	2	5	3	1	2	5	9	10	451
	23:00	1	183	49	0	1	0	3	0	0	0	1	0	1	239
Daily Total :		31	4533	990	8	32	24	28	54	7	43	25	89	152	6016
Percent :		1%	75%	16%	0%	1%	0%	0%	1%	0%	1%	0%	1%	3%	
Average :		1	189	41	0	1	1	1	2	0	2	1	4	6	249

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/12/18	00:00	3	292	52	0	2	2	3	1	0	2	1	2	2	362
Sun	01:00	0	182	36	0	0	0	0	0	0	0	0	3	0	221
	02:00	1	10	3	0	0	0	0	0	0	0	0	0	0	14
	03:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	04:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	05:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	06:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	07:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	08:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	09:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17:00	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	18:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19:00	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	20:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	21:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	22:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		6	484	91	0	2	2	3	1	0	2	1	5	2	599
Percent :		1%	81%	15%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	
Average :		0	20	4	0	0	0	0	0	0	0	0	0	0	24

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/13/18	00:00	2	139	45	0	4	2	1	0	0	0	0	0	0	193
Mon	01:00	2	322	63	0	3	1	4	1	0	0	0	1	0	397
	02:00	1	165	30	1	4	1	0	1	0	0	0	1	0	204
	03:00	2	104	18	0	2	0	0	0	0	0	0	1	0	127
	04:00	1	60	20	0	2	0	0	0	0	0	0	0	0	83
	05:00	3	79	69	0	4	4	0	0	0	0	0	0	0	159
	06:00	1	215	78	3	7	3	0	1	0	0	0	2	0	310
	07:00	1	166	63	0	7	3	0	0	0	0	0	2	1	243
	08:00	2	202	66	0	2	2	0	4	1	0	0	2	1	282
	09:00	0	245	72	0	2	2	0	0	0	0	0	1	0	322
	10:00	1	172	57	0	4	1	0	5	2	0	1	1	0	244
	11:00	1	206	94	1	4	1	2	1	1	0	0	2	1	314
	12:00	3	231	88	0	6	4	1	5	0	3	0	3	3	347
	13:00	2	236	99	0	4	3	3	4	0	1	2	1	2	357
	14:00	2	303	92	0	1	9	5	7	2	1	1	8	15	446
	15:00	1	363	84	0	2	0	4	6	0	4	3	19	28	514
	16:00	2	395	93	1	1	7	4	4	0	1	4	14	22	548
	17:00	5	317	89	0	2	5	4	8	1	5	4	4	8	452
	18:00	1	305	64	2	1	2	1	7	3	0	2	5	15	408
	19:00	7	254	55	0	2	6	2	3	1	3	7	24	52	416
	20:00	3	213	49	2	1	9	5	5	2	3	6	16	44	358
	21:00	8	374	70	0	1	10	6	3	1	5	1	11	19	509
	22:00	0	338	75	2	0	5	4	4	0	4	1	9	20	462
	23:00	5	334	77	3	0	7	2	3	1	4	4	4	8	452
Daily Total :		56	5738	1610	15	66	87	48	72	15	34	36	131	239	8147
Percent :		1%	70%	20%	0%	1%	1%	1%	1%	0%	0%	0%	2%	3%	
Average :		2	239	67	1	3	4	2	3	1	1	2	5	10	340

(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/14/18	00:00	1	215	61	0	2	3	1	3	0	0	1	3	1	291
Tue	01:00	2	189	52	0	3	3	1	2	0	0	0	1	0	253
	02:00	1	100	19	0	5	2	1	0	0	0	0	0	0	128
	03:00	0	33	15	0	5	2	0	0	0	0	0	0	0	55
	04:00	3	36	19	1	4	3	0	1	0	0	0	0	0	67
	05:00	2	95	50	1	8	2	0	1	0	1	0	0	0	160
	06:00	0	179	82	0	13	4	0	1	0	0	0	0	1	280
	07:00	1	133	65	1	6	0	1	0	0	1	0	0	0	208
	08:00	0	133	38	0	8	2	0	1	0	0	0	0	0	182
	09:00	1	165	72	0	11	1	0	1	0	0	0	1	0	252
	10:00	1	103	71	0	6	0	2	1	1	0	0	0	0	185
	11:00	3	160	82	0	4	0	0	4	0	0	0	3	0	256
	12:00	1	185	80	0	6	0	1	0	0	0	0	3	0	276
	13:00	1	218	86	1	6	2	1	2	0	0	0	4	0	321
	14:00	2	301	103	0	5	0	0	3	1	5	0	6	7	433
	15:00	3	385	82	0	2	3	1	2	0	3	2	7	9	499
	16:00	4	378	103	1	2	4	4	2	2	6	3	4	7	520
	17:00	3	275	96	0	4	1	3	4	0	2	1	8	8	405
	18:00	2	282	93	1	2	3	3	6	0	1	0	12	16	421
	19:00	0	386	96	0	2	2	0	11	0	4	0	10	17	528
	20:00	2	355	79	0	2	2	1	1	1	3	1	10	14	471
	21:00	0	378	81	0	3	7	2	3	0	1	1	10	11	497
	22:00	2	283	92	0	2	8	0	1	0	0	0	5	4	397
	23:00	3	335	91	1	6	3	0	3	1	2	0	9	4	458
Daily Total :		38	5302	1708	7	117	57	22	53	6	29	9	96	99	7543
Percent :		1%	70%	23%	0%	2%	1%	0%	1%	0%	0%	0%	1%	1%	
Average :		2	221	71	0	5	2	1	2	0	1	0	4	4	313

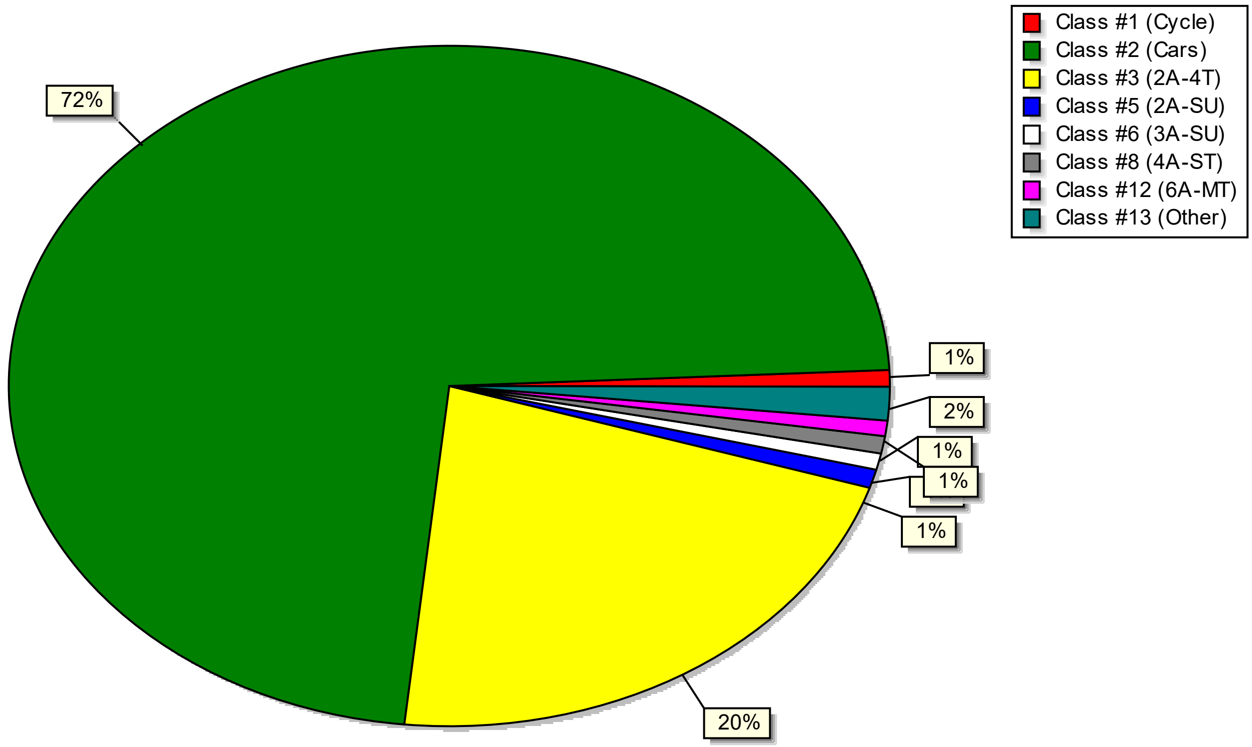
(DEFAULTC) Date	Time	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
08/15/18	00:00	0	200	64	0	8	2	1	1	0	0	0	0	0	276
Wed	01:00	2	93	20	0	2	3	0	0	0	0	0	0	0	120
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		2	293	84	0	10	5	1	1	0	0	0	0	0	396
Percent :		1%	74%	21%	0%	3%	1%	0%	0%	0%	0%	0%	0%	0%	
Average :		1	98	28	0	3	2	0	0	0	0	0	0	0	132

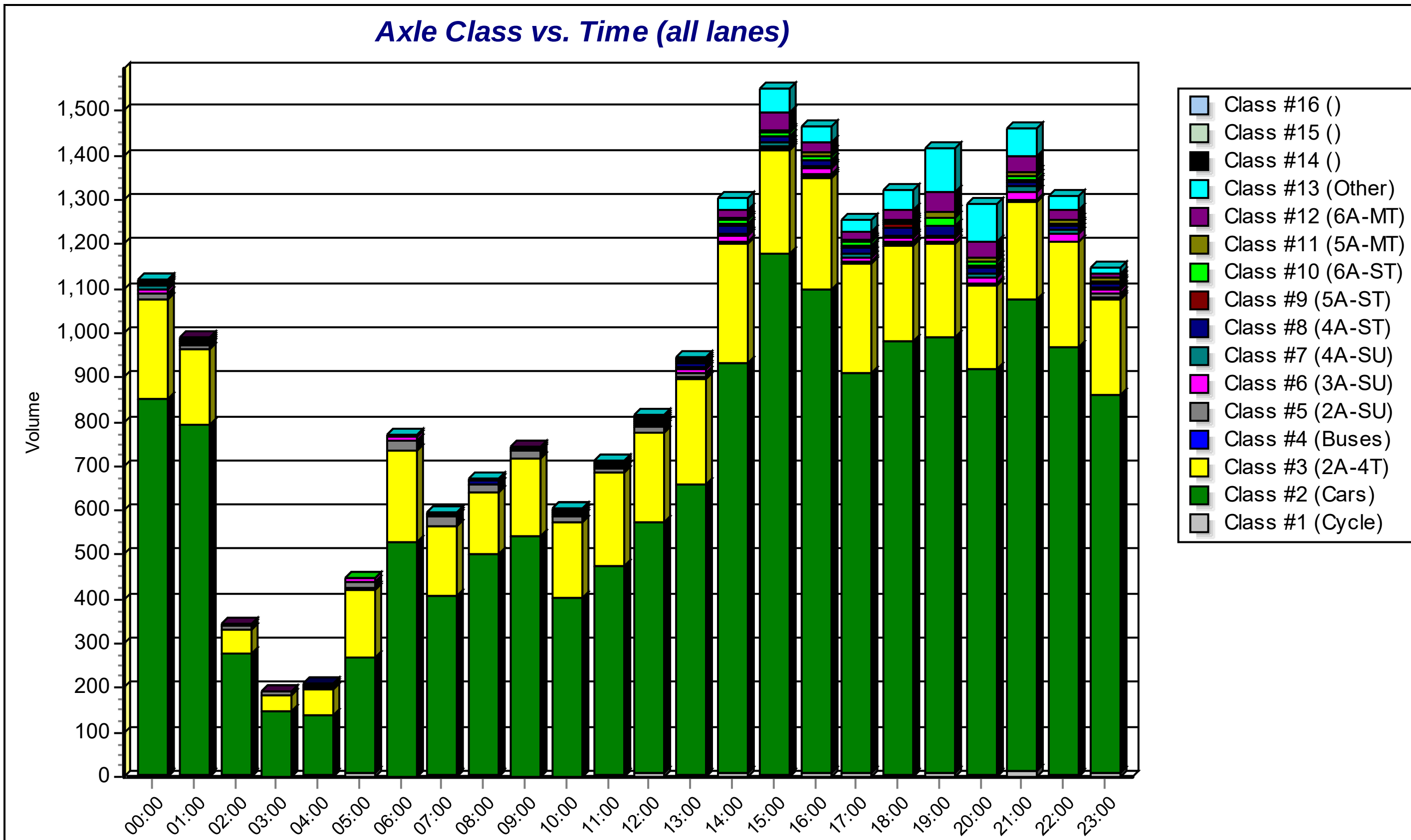
Basic Axle Class Summary: 236_046_VHB_ATR 11

(DEFAULTC) Description	Lane	#1 Cycle	#2 Cars	#3 2A-4T	#4 Buses	#5 2A-SU	#6 3A-SU	#7 4A-SU	#8 4A-ST	#9 5A-ST	#10 6A-ST	#11 5A-MT	#12 6A-MT	#13 Other	Total
TOTAL COUNT :	#1.	133	16350	4483	30	227	175	102	181	28	108	71	321	492	22701
		133	16350	4483	30	227	175	102	181	28	108	71	321	492	22701
Percents :	#1.	1%	72%	20%	0%	1%	1%	0%	1%	0%	0%	0%	1%	2%	100%
		1%	72%	20%	0%	1%	1%	0%	1%	0%	0%	0%	1%	2%	
Average :	#1.	1	164	45	0	2	2	1	2	0	1	1	3	5	227
		1	164	45	0	2	2	1	2	0	1	1	3	5	227
Days & ADT :	#1.	4.1	5448												
		4.1	5448												

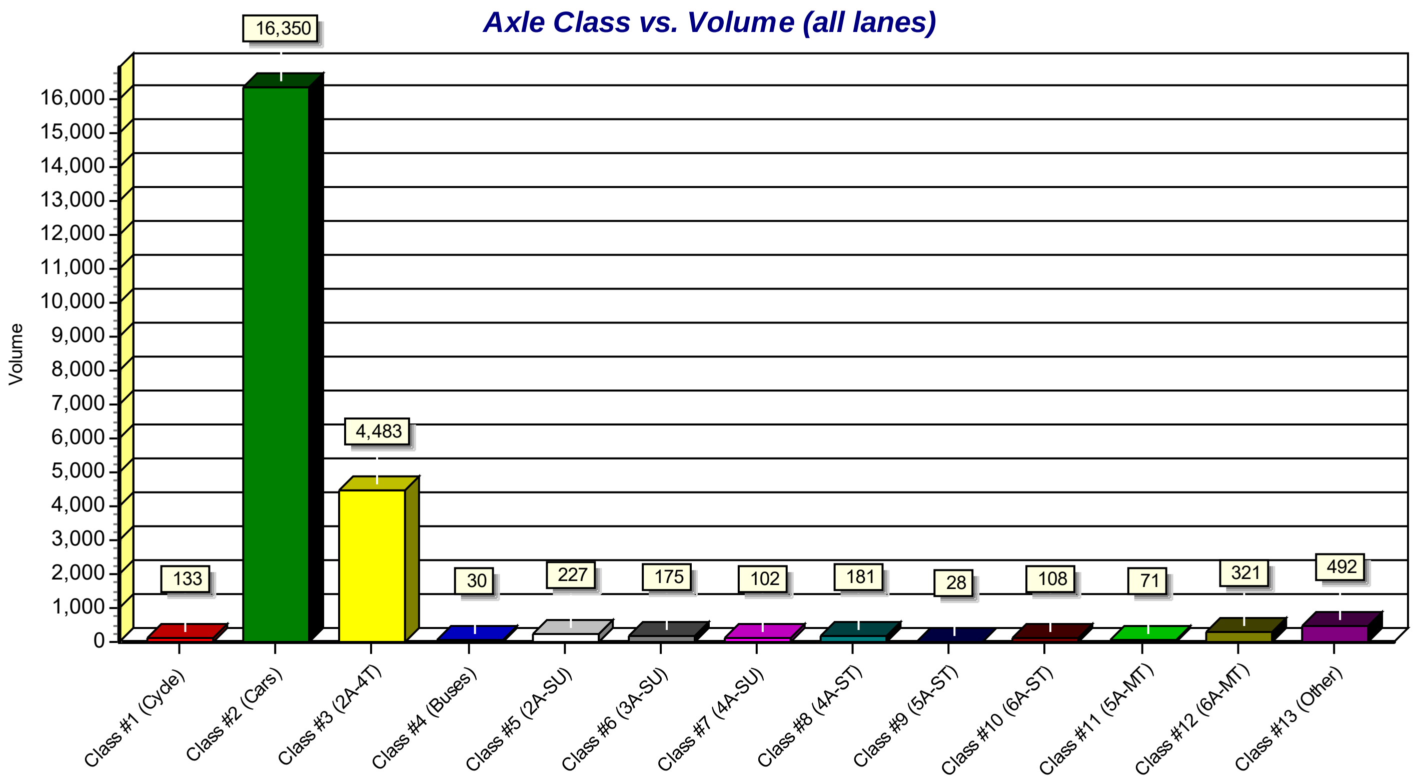
236_046_VHB_ATR 11 Axle Class Charts For Data From: 23:00 - 08/10/2018 To: 02:59 - 08/15/2018

Axle Class Percentages:





236_046_VHB_ATR 11 Axle Class Charts For Data From: 23:00 - 08/10/2018 To: 02:59 - 08/15/2018



Basic Speed Classification Report: 236_046_VHB_ATR

Lane #1 Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length	Comment
1.	W	West	Ax-Ax	3.0 ft	6.0 ft	

Lane #1 Basic Speed Classification Data From: 23:00 - 08/10/2018 To: 02:59 - 08/15/2018

(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
		0.0 -	20.0 -	25.0 -	30.0 -	35.0 -	40.0 -	45.0 -	50.0 -	55.0 -	60.0 -	65.0 -	70.0 -	75.0 -	80.0 -	85.0 -		
Date	Time	19.9	24.9	29.9	34.9	39.9	44.9	49.9	54.9	59.9	64.9	69.9	74.9	79.9	84.9	89.9	Other	Total
08/10/18	23:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Percent :		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Average :		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	227

Speeds - Average: 0.0 50% : 0.0 67% : 0.0 85% : 0.0 10mph Pace: 0.0 - 9.9 (0.0%)

(DEFAULTX) Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
08/11/18	00:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sat	01:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	03:00	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	3	12
	04:00	36	21	3	1	0	0	0	0	0	0	0	0	0	0	0	0	61
	05:00	63	57	11	0	0	0	0	0	0	0	0	0	0	0	0	0	131
	06:00	100	74	9	0	0	0	0	0	0	0	0	0	0	0	0	0	183
	07:00	104	35	5	0	0	0	0	0	0	0	0	0	0	0	0	0	144
	08:00	145	60	3	0	0	0	0	0	0	0	0	0	0	0	0	0	208
	09:00	123	44	4	0	0	0	0	0	0	0	0	0	0	0	0	0	171
	10:00	130	45	1	1	0	0	0	0	0	0	0	0	0	0	0	0	177
	11:00	86	52	5	0	0	0	0	0	0	0	0	0	0	0	0	0	143
	12:00	145	45	2	0	0	0	0	0	0	0	0	0	0	0	0	0	192
	13:00	214	52	1	0	0	0	0	0	0	0	0	0	0	0	0	0	267
	14:00	403	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	426
	15:00	523	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	538
	16:00	374	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	396
	17:00	369	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	395
	18:00	481	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	493
	19:00	461	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	470
	20:00	453	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	462
	21:00	450	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	457
	22:00	437	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	451
	23:00	188	50	1	0	0	0	0	0	0	0	0	0	0	0	0	0	239
Daily Total :		5289	677	45	2	0	0	0	0	0	0	0	0	0	0	0	3	6016
Percent :		88%	11%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		220	28	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Speeds - Average: 11.5 50% : 11.4 67% : 15.2 85% : 19.3 10mph Pace: 5.3 - 15.2 (45.4%)

Date	Time	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
08/12/18	00:00	313	47	2	0	0	0	0	0	0	0	0	0	0	0	0	0	362
Sun	01:00	138	78	4	1	0	0	0	0	0	0	0	0	0	0	0	0	221
	02:00	8	4	0	0	1	0	0	0	0	0	0	0	0	0	0	1	14
	03:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	04:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	05:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	06:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	07:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	08:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	09:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17:00	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	18:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19:00	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	20:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	21:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	22:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		461	129	6	1	1	0	0	0	0	0	0	0	0	0	0	1	599
Percent :		77%	22%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		19	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250

(DEFAULTX)

Speeds - Average: 12.9 50% : 12.2 67% : 16.3 85% : 22.1 10mph Pace: 5.7 - 15.6 (50.3%)

Date	Time	(DEFAULTX) #1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
08/13/18	00:00	95	82	14	2	0	0	0	0	0	0	0	0	0	0	0	0	193
Mon	01:00	107	235	55	0	0	0	0	0	0	0	0	0	0	0	0	0	397
	02:00	48	128	27	1	0	0	0	0	0	0	0	0	0	0	0	0	204
	03:00	33	72	20	2	0	0	0	0	0	0	0	0	0	0	0	0	127
	04:00	32	41	10	0	0	0	0	0	0	0	0	0	0	0	0	0	83
	05:00	57	77	21	4	0	0	0	0	0	0	0	0	0	0	0	0	159
	06:00	142	143	25	0	0	0	0	0	0	0	0	0	0	0	0	0	310
	07:00	104	122	17	0	0	0	0	0	0	0	0	0	0	0	0	0	243
	08:00	162	106	13	1	0	0	0	0	0	0	0	0	0	0	0	0	282
	09:00	177	121	22	2	0	0	0	0	0	0	0	0	0	0	0	0	322
	10:00	172	63	9	0	0	0	0	0	0	0	0	0	0	0	0	0	244
	11:00	244	63	7	0	0	0	0	0	0	0	0	0	0	0	0	0	314
	12:00	271	72	4	0	0	0	0	0	0	0	0	0	0	0	0	0	347
	13:00	289	63	5	0	0	0	0	0	0	0	0	0	0	0	0	0	357
	14:00	412	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	446
	15:00	470	41	3	0	0	0	0	0	0	0	0	0	0	0	0	0	514
	16:00	519	27	2	0	0	0	0	0	0	0	0	0	0	0	0	0	548
	17:00	416	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	452
	18:00	386	20	2	0	0	0	0	0	0	0	0	0	0	0	0	0	408
	19:00	406	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	416
	20:00	349	6	0	2	1	0	0	0	0	0	0	0	0	0	0	0	358
	21:00	489	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	509
	22:00	448	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	462
	23:00	405	44	3	0	0	0	0	0	0	0	0	0	0	0	0	0	452
Daily Total :		6233	1640	259	14	1	0	0	0	0	0	0	0	0	0	0	0	8147
Percent :		77%	20%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		260	68	11	1	0	0	0	0	0	0	0	0	0	0	0	0	24

Speeds - Average: 13.1 50% : 13.0 67% : 17.5 85% : 22.2 10mph Pace: 5.9 - 15.8 (39.2%)

(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
Date	Time	0.0 - 19.9	20.0 - 24.9	25.0 - 29.9	30.0 - 34.9	35.0 - 39.9	40.0 - 44.9	45.0 - 49.9	50.0 - 54.9	55.0 - 59.9	60.0 - 64.9	65.0 - 69.9	70.0 - 74.9	75.0 - 79.9	80.0 - 84.9	85.0 - 89.9	Other	Total
08/14/18	00:00	181	95	15	0	0	0	0	0	0	0	0	0	0	0	0	0	291
Tue	01:00	113	121	19	0	0	0	0	0	0	0	0	0	0	0	0	0	253
	02:00	40	72	15	1	0	0	0	0	0	0	0	0	0	0	0	0	128
	03:00	23	22	9	1	0	0	0	0	0	0	0	0	0	0	0	0	55
	04:00	29	32	5	1	0	0	0	0	0	0	0	0	0	0	0	0	67
	05:00	62	77	19	2	0	0	0	0	0	0	0	0	0	0	0	0	160
	06:00	133	126	20	1	0	0	0	0	0	0	0	0	0	0	0	0	280
	07:00	91	100	17	0	0	0	0	0	0	0	0	0	0	0	0	0	208
	08:00	78	81	21	2	0	0	0	0	0	0	0	0	0	0	0	0	182
	09:00	128	112	12	0	0	0	0	0	0	0	0	0	0	0	0	0	252
	10:00	106	68	11	0	0	0	0	0	0	0	0	0	0	0	0	0	185
	11:00	145	96	14	1	0	0	0	0	0	0	0	0	0	0	0	0	256
	12:00	124	121	29	2	0	0	0	0	0	0	0	0	0	0	0	0	276
	13:00	190	112	19	0	0	0	0	0	0	0	0	0	0	0	0	0	321
	14:00	380	49	4	0	0	0	0	0	0	0	0	0	0	0	0	0	433
	15:00	471	26	2	0	0	0	0	0	0	0	0	0	0	0	0	0	499
	16:00	460	55	3	2	0	0	0	0	0	0	0	0	0	0	0	0	520
	17:00	336	65	4	0	0	0	0	0	0	0	0	0	0	0	0	0	405
	18:00	398	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	421
	19:00	510	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	528
	20:00	464	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	471
	21:00	478	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	497
	22:00	327	67	3	0	0	0	0	0	0	0	0	0	0	0	0	0	397
	23:00	395	60	3	0	0	0	0	0	0	0	0	0	0	0	0	0	458
Daily Total :		5662	1624	244	13	0	0	0	0	0	0	0	0	0	0	0	0	7543
Percent :		75%	22%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		236	68	10	1	0	0	0	0	0	0	0	0	0	0	0	0	340

Speeds - Average: 13.2 50% : 13.3 67% : 17.8 85% : 22.4 10mph Pace: 15.0 - 24.9 (40.1%)

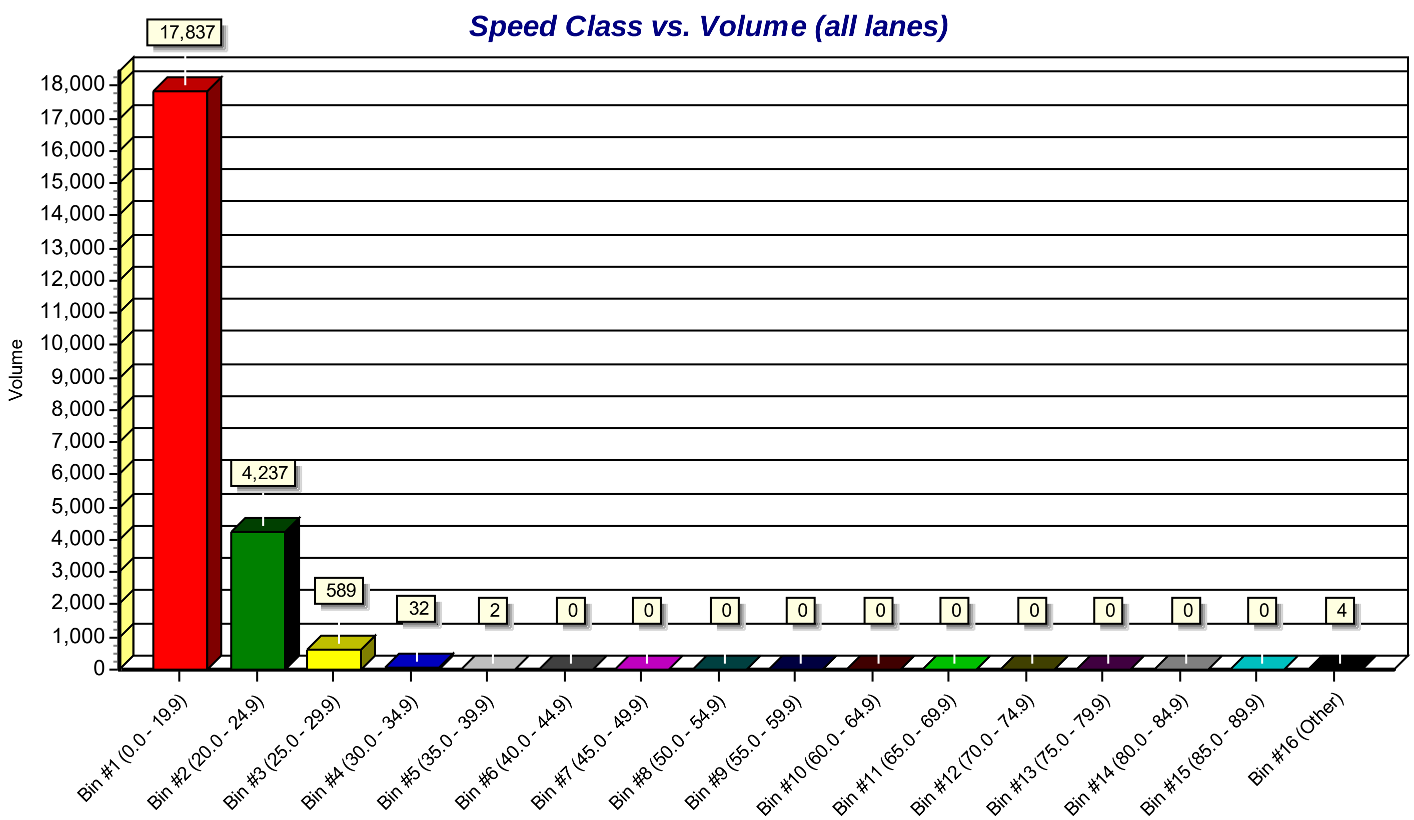
(DEFAULTX)		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
Date	Time	0.0 - 19.9	20.0 - 24.9	25.0 - 29.9	30.0 - 34.9	35.0 - 39.9	40.0 - 44.9	45.0 - 49.9	50.0 - 54.9	55.0 - 59.9	60.0 - 64.9	65.0 - 69.9	70.0 - 74.9	75.0 - 79.9	80.0 - 84.9	85.0 - 89.9	Other	Total
08/15/18	00:00	132	111	31	2	0	0	0	0	0	0	0	0	0	0	0	0	276
Wed	01:00	60	56	4	0	0	0	0	0	0	0	0	0	0	0	0	0	120
	02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daily Total :		192	167	35	2	0	0	0	0	0	0	0	0	0	0	0	0	396
Percent :		48%	42%	9%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :		64	56	12	1	0	0	0	0	0	0	0	0	0	0	0	0	315

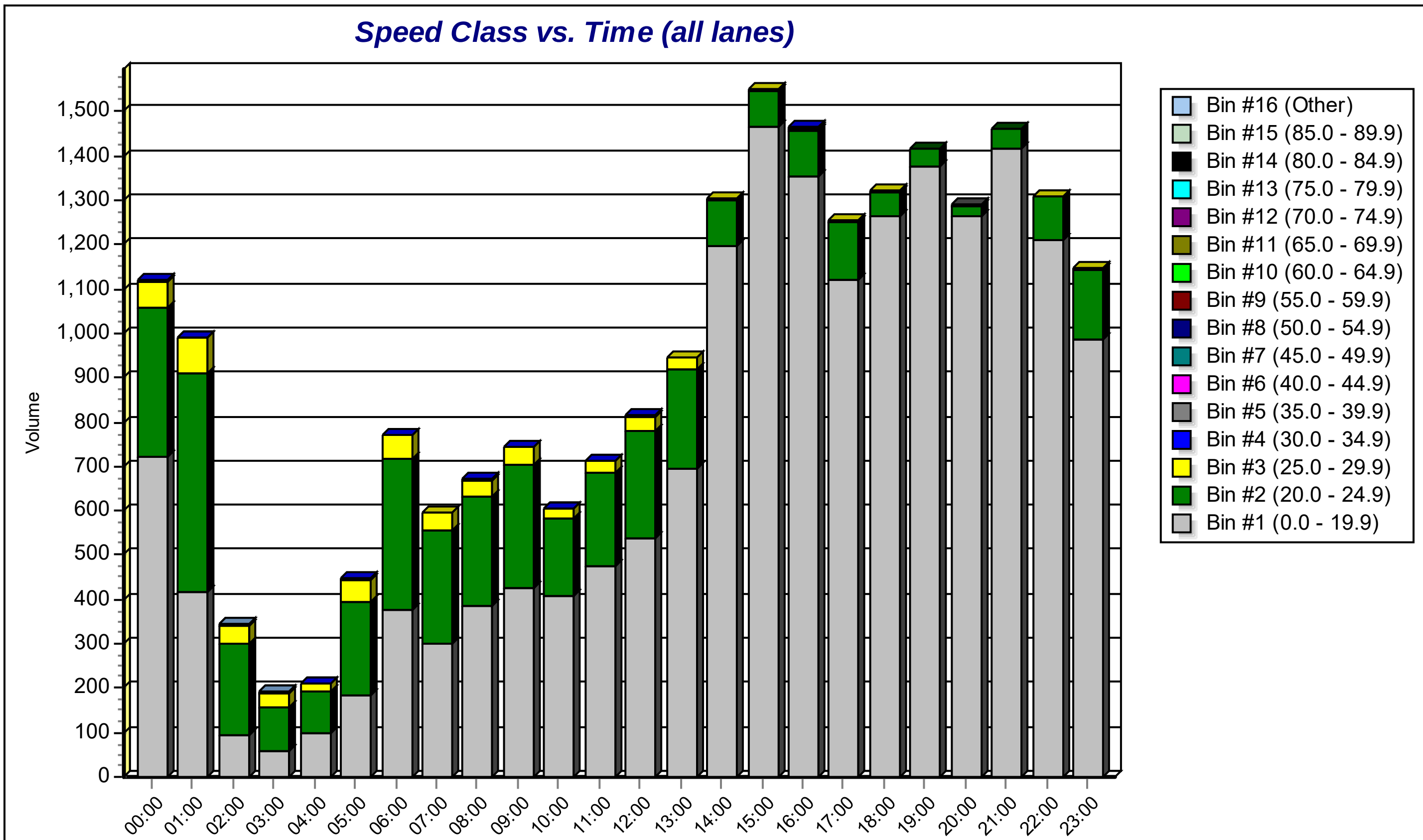
Speeds - Average: 16.9 50% : 20.3 67% : 22.3 85% : 24.3 10mph Pace: 20.1 - 30.0 (51.0%)

Basic Speed Class Summary: 236_046_VHB_ATR 11

(DEFAULTX) Description	Lane	#1 0.0 - 19.9	#2 20.0 - 24.9	#3 25.0 - 29.9	#4 30.0 - 34.9	#5 35.0 - 39.9	#6 40.0 - 44.9	#7 45.0 - 49.9	#8 50.0 - 54.9	#9 55.0 - 59.9	#10 60.0 - 64.9	#11 65.0 - 69.9	#12 70.0 - 74.9	#13 75.0 - 79.9	#14 80.0 - 84.9	#15 85.0 - 89.9	#16 Other	Total
TOTAL COUNT :	#1.	17837	4237	589	32	2	0	0	0	0	0	0	0	0	0	0	4	22701
		17837	4237	589	32	2	0	0	0	0	0	0	0	0	0	0	4	22701
Percents :	#1.	79%	19%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
		79%	19%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Average :	#1.	178	42	6	0	0	0	0	0	0	0	0	0	0	0	0	0	226
		178	42	6	0	0	0	0	0	0	0	0	0	0	0	0	0	226
Days & ADT :	#1.	4.1	5448															
		4.1	5448															
Avg,50,67,85%:	#1.	12.8	12.7	17.1	21.8	5.7	- 15.6	40%										
		12.8	12.7	17.1	21.8	5.7	- 15.6	40%										

236_046_VHB_ATR 11 Speed Class Charts For Data From: 23:00 - 08/10/2018 To: 02:59 - 08/15/2018





Basic Volume Report: 236_046_VHB_ATR 11

Station ID : 236_046_VHB_ATR 11
Info Line 1 : Terminal E Arrival Curb 2 Exit
Info Line 2 : Logan Airport
GPS Lat/Lon :
DB File : 236046VHBATR 11.DB

Last Connected Device Type : RoadRunner3
Version Number : 1.32
Serial Number : 17751
Number of Lanes : 1
Posted Speed Limit : 0.0 mph

Lane #1 Configuration

#	Dir.	Information	Volume Mode	Volume Sensors	Divide By 2	Comment
1.	W	West	Normal	Veh.	No	

Lane #1 Basic Volume Data From: 23:00 - 08/10/2018 To: 03:29 - 08/15/2018

Date	Time	:00	:15	:30	:45	Total
08/10/18	23:00	0	0	0	0	0
Day Total :						0

AM Total :		Peak AM Hour :		Peak AM Factor :	Average Period :	0.0
PM Total :	0 (0.0%)	Peak PM Hour :		Peak PM Factor :	Average Hour :	0.0

Date	Time	:00	:15	:30	:45	Total
08/11/18	00:00	0	0	0	0	0
Sat	01:00	0	0	0	0	0
	02:00	0	0	0	0	0
	03:00	0	0	3	9	12
	04:00	11	8	23	19	61
	05:00	19	19	38	55	131
	06:00	53	44	50	36	183
	07:00	25	25	46	48	144
	08:00	51	46	58	53	208
	09:00	41	65	42	23	171
	10:00	43	42	57	35	177
	11:00	32	48	41	22	143
	12:00	31	38	50	73	192
	13:00	74	57	62	74	267
	14:00	107	119	104	96	426
	15:00	140	137	119	142	538
	16:00	123	105	76	92	396
	17:00	96	100	100	99	395
	18:00	119	110	128	136	493
	19:00	110	113	120	127	470
	20:00	138	103	112	109	462
	21:00	90	108	135	124	457
	22:00	130	128	97	96	451
	23:00	54	64	64	57	239
Day Total :						6016

AM Total :	1230 (20.4%)	Peak AM Hour : 08:30 =	217 (3.6%)	Peak AM Factor : 0.835	Average Period :	62.7
PM Total :	4786 (79.6%)	Peak PM Hour : 15:00 =	538 (8.9%)	Peak PM Factor : 0.947	Average Hour :	250.7

Date	Time	:00	:15	:30	:45	Total
08/12/18	00:00	49	80	118	115	362
Sun	01:00	90	62	42	27	221
	02:00	8	6	0	0	14
	03:00	0	0	0	0	0
	04:00	0	0	0	0	0
	05:00	0	0	0	0	0
	06:00	0	0	0	0	0
	07:00	0	0	0	0	0
	08:00	0	0	0	0	0
	09:00	0	0	0	0	0
	10:00	0	0	0	0	0
	11:00	0	0	0	0	0
	12:00	0	0	0	0	0
	13:00	0	0	0	0	0
	14:00	0	0	0	0	0
	15:00	0	0	0	0	0
	16:00	0	0	0	0	0
	17:00	0	0	0	1	1
	18:00	0	0	0	0	0
	19:00	0	0	0	1	1
	20:00	0	0	0	0	0
	21:00	0	0	0	0	0
	22:00	0	0	0	0	0
	23:00	0	0	0	0	0
Day Total :						599

AM Total :	597 (99.7%)	Peak AM Hour : 00:15 =	403 (67.3%)	Peak AM Factor :	0.854	Average Period :	6.2
PM Total :	2 (0.3%)	Peak PM Hour : 17:00 =	1 (0.2%)	Peak PM Factor :	0.250	Average Hour :	25.0

Date	Time	:00	:15	:30	:45	Total
08/13/18	00:00	0	32	69	92	193
Mon	01:00	121	61	120	95	397
	02:00	64	39	66	35	204
	03:00	36	43	14	34	127
	04:00	17	9	15	42	83
	05:00	38	36	40	45	159
	06:00	76	89	77	68	310
	07:00	81	49	49	64	243
	08:00	70	66	68	78	282
	09:00	80	75	103	64	322
	10:00	73	54	60	57	244
	11:00	43	63	91	117	314
	12:00	108	73	84	82	347
	13:00	105	90	88	74	357
	14:00	112	103	118	113	446
	15:00	133	141	112	128	514
	16:00	156	147	125	120	548
	17:00	113	132	114	93	452
	18:00	99	110	92	107	408
	19:00	106	87	121	102	416
	20:00	125	102	77	54	358
	21:00	159	128	130	92	509
	22:00	108	107	118	129	462
	23:00	131	97	114	110	452
Day Total :						8147

AM Total :	2878 (35.3%)	Peak AM Hour : 01:00 =	397 (4.9%)	Peak AM Factor : 0.820		Average Period :	84.9
PM Total :	5269 (64.7%)	Peak PM Hour : 15:45 =	556 (6.8%)	Peak PM Factor : 0.874		Average Hour :	339.5

Date	Time	:00	:15	:30	:45	Total
08/14/18	00:00	74	82	86	49	291
Tue	01:00	101	45	58	49	253
	02:00	43	56	13	16	128
	03:00	32	10	7	6	55
	04:00	10	11	26	20	67
	05:00	20	54	48	38	160
	06:00	61	53	93	73	280
	07:00	55	47	58	48	208
	08:00	32	47	41	62	182
	09:00	51	68	89	44	252
	10:00	50	49	37	49	185
	11:00	67	66	50	73	256
	12:00	80	62	55	79	276
	13:00	77	85	67	92	321
	14:00	104	109	121	99	433
	15:00	111	101	156	131	499
	16:00	121	110	159	130	520
	17:00	103	106	94	102	405
	18:00	96	78	123	124	421
	19:00	118	139	123	148	528
	20:00	132	124	96	119	471
	21:00	121	135	116	125	497
	22:00	92	113	98	94	397
	23:00	119	131	106	102	458
Day Total :						7543

AM Total :	2317 (30.7%)	Peak AM Hour : 00:15 =	318 (4.2%)	Peak AM Factor : 0.787		Average Period :	78.6
PM Total :	5226 (69.3%)	Peak PM Hour : 19:15 =	542 (7.2%)	Peak PM Factor : 0.852		Average Hour :	314.3

Date	Time	:00	:15	:30	:45	Total
08/15/18	00:00	69	61	75	71	276
Wed	01:00	78	42	0	0	120
	02:00	0	0	0	0	0
Day Total :						396

AM Total :	396 (100.0%)	Peak AM Hour : 00:15 =	285 (72.0%)	Peak AM Factor : 0.913		Average Period :	33.0
PM Total :		Peak PM Hour :		Peak PM Factor :		Average Hour :	132.0

Basic Volume Summary: 236_046_VHB_ATR 11

Grand Total For Data From: 23:00 - 08/10/2018 To: 03:29 - 08/15/2018

Lane	Total Count		# Of Days	ADT	Avg. Period	Avg. Hour	AM Total & Percent	PM Total & Percent
#1.	22701	(100.0%)	4.17	5448	56.8	227.0	7418 (32.7%)	15283 (67.3%)
ALL	22701		4.17	5448	56.8	227.0	7418 (32.7%)	15283 (67.3%)

Lane	Peak AM Hour		Date	Peak AM Factor	Peak PM Hour		Date	Peak PM Factor
#1.	00:15 =	403	08/12/2018	0.854	15:45 =	556	08/13/2018	0.874

Crash Data

Crash Date	Crash Time	Crash Severity	Maximum Injury Severity Reported	Number of NonFatal Injuries	Number of Fatal Injuries	Manner of Collision	Vehicle Action Prior to Crash	Vehicle Travel Directions	First Harmful Event	Most Harmful Events	Vehicle Sequence of Events	Vehicle Configuration	Non Motorist Type	Road Surface	Ambient Light	Weather Condition	Roadway	Near Intersection Roadway
8/22/2015	4:44 PM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Parked / V2:Backing	V1:W / V2:W	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires)		Dry	Daylight	Cloudy	LOGAN AIRPORT TERMINAL E	AIRPORT ROAD-DEPARTURE LEVEL
1/6/2015	10:40 AM	Property damage only (none injured)	No injury	0	0	Sideswipe, same direction	V1: Turning right	V1:W	Collision with pedestrian	V1:(Collision with pedestrian)	V1:(Collision with pedestrian)	V1:(Passenger car)	P1:Pedestrian	Dry	Daylight	Clear	AIRPORT ROAD-DEPARTURE LEVEL	LOGAN AIRPORT TERMINAL E
7/12/2015	10:18 AM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Slowing or stopped in traffic / V2:Slowing or stopped in traffic	V1:W / V2:W	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Passenger car)		Dry	Daylight	Clear	AIRPORT ROAD-DEPARTURE LEVEL / LOGAN AIRPORT TERMINAL E	
10/28/2016	6:23 PM	Property damage only (none injured)	No injury	0	0	Angle	V1: Travelling straight ahead / V2:Travelling straight ahead	V1:S / V2:S	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires)		Wet	Dark - lighted roadway	Not Reported	LOGAN AIRPORT TERMINAL E	AIRPORT ROAD-DEPARTURE LEVEL

Crash Date	Crash Time	Crash Severity	Maximum Injury Severity Reported	Number of NonFatal Injuries	Number of Fatal Injuries	Manner of Collision	Vehicle Action Prior to Crash	Vehicle Travel Directions	First Harmful Event	Most Harmful Events	Vehicle Sequence of Events	Vehicle Configuration	Non Motorist Type	Road Surface	Ambient Light	Weather Condition	Roadway	Near Intersection Roadway
5/30/2016	4:09 PM	Property damage only (none injured)	No injury	0	0	Sideswipe, same direction	V1: Turning left / V2:Travelling straight ahead	V1:N / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires) V2:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires)		Wet	Daylight	Cloudy	AIRPORT ROAD-DEPARTURE LEVEL	LOGAN AIRPORT TERMINAL E
3/27/2015	3:41 PM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Entering traffic lane / V2:Entering traffic lane	V1:W / V2:W	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires) V2:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires)		Dry	Daylight	Cloudy	LOGAN AIRPORT TERMINAL E	AIRPORT ROAD-DEPARTURE LEVEL
5/27/2014	8:55 PM	Property damage only (none injured)	No injury	0	0	Sideswipe, same direction	V1: Changing lanes / V2:Travelling straight ahead	V1:W / V2:W	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Passenger car)		Wet	Dark - lighted roadway	Rain	AIRPORT ROAD - DEPARTURE LEVEL	RAMP - AIRPORT ROAD TO RT 90 WB

Crash Date	Crash Time	Crash Severity	Maximum Injury Severity Reported	Number of NonFatal Injuries	Number of Fatal Injuries	Manner of Collision	Vehicle Action Prior to Crash	Vehicle Travel Directions	First Harmful Event	Most Harmful Events	Vehicle Sequence of Events	Vehicle Configuration	Non Motorist Type	Road Surface	Ambient Light	Weather Condition	Roadway	Near Intersection Roadway
5/20/2015	4:25 PM	Property damage only (none injured)	No injury	0	0	Angle	V1: Turning left / V2:Slowing or stopped in traffic	V1:E / V2:S	Collision with motor vehicle in traffic	V1:() V2:()	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires)		Dry	Daylight	Not Reported	AIRPORT ROAD-DEPARTURE LEVEL / CENTRAL PARKING ACCESS ROAD	
5/27/2014	8:55 PM	Property damage only (none injured)	No injury	0	0	Sideswipe, same direction	V1: Changing lanes / V2:Travelling straight ahead	V1:W / V2:W	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Passenger car)		Wet	Dark - lighted roadway	Rain	AIRPORT ROAD - DEPARTURE LEVEL	RAMP - AIRPORT ROAD TO RT 90 WB
8/7/2014	9:28 AM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Backing / V2:Parked	V1:8 / V2:8	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with parked motor vehicle)	V1:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires) V2:(Passenger car)		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	LOGAN AIRPORT TERMINAL E
10/15/2014	9:00 PM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Travelling straight ahead / V2:Slowing or stopped in traffic	V1:W / V2:W	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Passenger car)		Dry	Dark - lighted roadway	Not Reported	LOGAN AIRPORT TERMINAL E	LOGAN AIRPORT TERMINAL E
7/7/2015	9:25 PM	Non-fatal injury	Non-fatal injury - Incapacitating	2	0	Rear-end	V1: Slowing or stopped in traffic / V2:Slowing or stopped in traffic	V1:S / V2:S	Collision with pedestrian	V1:(Collision with pedestrian) V2:(Collision with pedestrian)	V1:(Collision with pedestrian) V2:(Collision with pedestrian)	V1:(Passenger car) V2:(Passenger car)		Dry	Dark - lighted roadway	Clear	LOGAN AIRPORT TERMINAL E	LOGAN AIRPORT TERMINAL E

Crash Date	Crash Time	Crash Severity	Maximum Injury Severity Reported	Number of NonFatal Injuries	Number of Fatal Injuries	Manner of Collision	Vehicle Action Prior to Crash	Vehicle Travel Directions	First Harmful Event	Most Harmful Events	Vehicle Sequence of Events	Vehicle Configuration	Non Motorist Type	Road Surface	Ambient Light	Weather Condition	Roadway	Near Intersection Roadway
6/21/2015	7:15 PM	Property damage only (none injured)	No injury	0	0	Sideswipe, same direction	V1: Changing lanes / V2:Travelling straight ahead	V1:E / V2:E	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Bus (seats for 7-15 people, including driver))		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	LOGAN AIRPORT TERMINAL E
7/11/2015	1:04 PM	Property damage only (none injured)	No injury	0	0	Sideswipe, same direction	V1: Turning right / V2:Parked	V1:N / V2:8	Collision with parked motor vehicle	V1:(Collision with parked motor vehicle) V2:(Collision with motor vehicle in traffic)	V1:(Collision with parked motor vehicle) V2:(Collision with motor vehicle in traffic)	V1:(Bus (seats for 7-15 people, including driver)) V2:(Passenger car)		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	AIRPORT ROAD-DEPARTURE LEVEL
8/9/2015	2:28 PM	Property damage only (none injured)	No injury	0	0	Angle	V1: Turning left / V2:Turning left	V1:8 / V2:8	Not reported	V1:() V2:()	V2:	V1:(Bus (seats for more than 15 people, including driver)) V2:(Passenger car)		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	RAMP-TERMINAL E TO RT 90 EB/E BOSTON EXP
9/14/2015	1:43 PM	Property damage only (none injured)	No injury	0	0	Sideswipe, same direction	V1: Travelling straight ahead / V2:Not reported	V1:N / V2:8	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:()	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Bus (seats for more than 15 people, including driver)) V2:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires)		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	RAMP-TERMINAL E TO RT 90 EB/E BOSTON EXP

Crash Date	Crash Time	Crash Severity	Maximum Injury Severity Reported	Number of NonFatal Injuries	Number of Fatal Injuries	Manner of Collision	Vehicle Action Prior to Crash	Vehicle Travel Directions	First Harmful Event	Most Harmful Events	Vehicle Sequence of Events	Vehicle Configuration	Non Motorist Type	Road Surface	Ambient Light	Weather Condition	Roadway	Near Intersection Roadway
12/23/2015	7:00 AM	Property damage only (none injured)	No injury	0	0	Sideswipe, same direction	V1: Changing lanes / V2:Parked	V1:N / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Bus (seats for more than 15 people, including driver)) V2:(Passenger car)		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	RAMP-TERMINAL E TO RT 90 EB/E BOSTON EXP
5/16/2016	4:30 PM	Property damage only (none injured)	No injury	0	0	Sideswipe, same direction	V1: Parked / V2:Overtaking/passing	V1:N / V2:N	Collision with parked motor vehicle	V1:(Collision with motor vehicle in traffic) V2:(Collision with parked motor vehicle)	V1:(Collision with motor vehicle in traffic) V2:(Collision with parked motor vehicle)	V1:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires) V2:(Bus (seats for more than 15 people, including driver))		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	LOGAN AIRPORT TERMINAL E
5/20/2016	7:10 PM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Travelling straight ahead / V2:Slowing or stopped in traffic	V1:N / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires) V2:(Passenger car)		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	LOGAN AIRPORT TERMINAL E

Crash Date	Crash Time	Crash Severity	Maximum Injury Severity Reported	Number of NonFatal Injuries	Number of Fatal Injuries	Manner of Collision	Vehicle Action Prior to Crash	Vehicle Travel Directions	First Harmful Event	Most Harmful Events	Vehicle Sequence of Events	Vehicle Configuration	Non Motorist Type	Road Surface	Ambient Light	Weather Condition	Roadway	Near Intersection Roadway
5/25/2016	9:20 AM	Property damage only (none injured)	No injury	0	0	Single vehicle crash	V1: Travelling straight ahead	V1:8	Collision with bridge overhead structure	V1:()	V1:(Collision with bridge overhead structure)	V1:(Single-unit truck (2-axle, 6-tire))		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	LOGAN AIRPORT TERMINAL B
7/12/2016	8:29 PM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Travelling straight ahead / V2:Slowing or stopped in traffic	V1:S / V2:S	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires) V2:(Passenger car)		Dry	Dusk	Clear/Cloudy	LOGAN AIRPORT TERMINAL E	LOGAN AIRPORT TERMINAL E
8/31/2014	10:47 PM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Slowing or stopped in traffic / V2:Not reported	V1:S / V2:S	Collision with motor vehicle in traffic	V1:() V2:()	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Passenger car)		Wet	Dark - lighted roadway	Cloudy/Rain	LOGAN AIRPORT TERMINAL E	
2/18/2016	8:50 AM	Non-fatal injury	Non-fatal injury - Non-incapacitating	2	0	Sideswipe, same direction	V1: Travelling straight ahead / V2:Slowing or stopped in traffic	V1:W / V2:W	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Bus (seats for more than 15 people, including driver))		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	
11/2/2016	8:34 AM	Property damage only (none injured)	No injury	0	0	Angle	V1: Slowing or stopped in traffic / V2:Slowing or stopped in traffic	V1:N / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires)		Dry	Daylight	Not Reported	LOGAN AIRPORT TERMINAL B	LOGAN AIRPORT TERMINAL E

Crash Date	Crash Time	Crash Severity	Maximum Injury Severity Reported	Number of NonFatal Injuries	Number of Fatal Injuries	Manner of Collision	Vehicle Action Prior to Crash	Vehicle Travel Directions	First Harmful Event	Most Harmful Events	Vehicle Sequence of Events	Vehicle Configuration	Non Motorist Type	Road Surface	Ambient Light	Weather Condition	Roadway	Near Intersection Roadway
8/11/2015	1:30 AM	Property damage only (none injured)	No injury	0	0	Single vehicle crash	V1: Turning left	V1:8	Collision with other	V1:(Collision with median barrier)	V1:(Collision with impact attenuator/crash cushion),(Collision with median barrier)	V1:(Passenger car)		Dry	Dark - lighted roadway	Clear	LOGAN AIRPORT TERMINAL E	SERVICE ROAD
5/18/2015	4:50 PM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Travelling straight ahead / V2:Entering traffic lane	V1:N / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Passenger car)		Dry	Daylight	Clear	LOGAN AIRPORT TERMINAL E	SERVICE ROAD
9/16/2016	9:10 AM	Property damage only (none injured)	No injury	0	0	Angle	V1: Turning left / V2:Travelling straight ahead	V1:S / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Passenger car)		Dry	Daylight	Clear	SERVICE ROAD	HOTEL DRIVE
12/11/2014	9:15 AM	Property damage only (none injured)	No injury	0	0	Head-on	V1: Travelling straight ahead / V2:Turning left	V1:E / V2:W	Collision with motor vehicle in traffic	V1:() V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Passenger car)		Wet	Daylight	Cloudy	HOTEL DRIVE / SERVICE ROAD	
5/27/2014	6:23 PM	Property damage only (none injured)	No injury	0	0	Angle	V1: Travelling straight ahead / V2:Turning left	V1:N / V2:W	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Passenger car)		Wet	Daylight	Rain	SR-2	LOGAN AIRPORT TERMINAL E

Crash Date	Crash Time	Crash Severity	Maximum Injury Severity Reported	Number of NonFatal Injuries	Number of Fatal Injuries	Manner of Collision	Vehicle Action Prior to Crash	Vehicle Travel Directions	First Harmful Event	Most Harmful Events	Vehicle Sequence of Events	Vehicle Configuration	Non Motorist Type	Road Surface	Ambient Light	Weather Condition	Roadway	Near Intersection Roadway
1/28/2015	1:15 PM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Slowing or stopped in traffic / V2:Slowing or stopped in traffic	V1:E / V2:E	Collision with motor vehicle in traffic	V1:() V2:()	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires) V2:(Passenger car)		Snow	Daylight	Clear	HOTEL DRIVE / SERVICE ROAD	
6/10/2014	6:30 PM	Property damage only (none injured)	No injury	0	0	Sideswipe, opposite direction	V1: Slowing or stopped in traffic / V2:Turning left	V1:S / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Passenger car)		Dry	Daylight	Not Reported	SERVICE ROAD	LOGAN AIRPORT TERMINAL E
11/24/2016	3:51 AM	Property damage only (none injured)	No injury	0	0	Single vehicle crash	V1: Travelling straight ahead	V1:E	Collision with median barrier	V1:(Collision with median barrier)	V1:(Collision with median barrier)	V1:(Passenger car)		Dry	Dark - lighted roadway	Clear	Rte 90 E	
5/22/2016	1:22 AM	Non-fatal injury	Non-fatal injury - Possible	1	0	Single vehicle crash	V1: Travelling straight ahead	V1:E	Collision with guardrail	V1:(Collision with median barrier)	V1:(Collision with median barrier)	V1:(Passenger car)		Dry	Dark - lighted roadway	Clear	Rte 90 E	
5/23/2015	9:03 PM	Non-fatal injury	Non-fatal injury - Possible	1	0	Single vehicle crash	V1: Travelling straight ahead	V1:E	Collision with median barrier	V1:(Collision with median barrier)	V1:(Ran off road left),(Collision with median barrier)	V1:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires)		Dry	Dark - lighted roadway	Clear	Rte 90 E	UNKNOWN
5/22/2016	1:44 AM	Property damage only (none injured)	No injury	0	0	Single vehicle crash	V1: Travelling straight ahead	V1:E	Collision with median barrier	V1:(Collision with median barrier)	V1:(Collision with median barrier)	V1:(Passenger car)		Dry	Dark - lighted roadway	Clear	Rte 90 E	
8/27/2016	12:23 AM	Property damage only (none injured)	No injury	0	0	Single vehicle crash	V1: Travelling straight ahead	V1:W	Collision with median barrier	V1:(Collision with median barrier)	V1:(Collision with median barrier)	V1:(Passenger car)		Dry	Dark - lighted roadway	Clear	SERVICE ROAD	AIRPORT STATION BUS ACCESS

Crash Date	Crash Time	Crash Severity	Maximum Injury Severity Reported	Number of NonFatal Injuries	Number of Fatal Injuries	Manner of Collision	Vehicle Action Prior to Crash	Vehicle Travel Directions	First Harmful Event	Most Harmful Events	Vehicle Sequence of Events	Vehicle Configuration	Non Motorist Type	Road Surface	Ambient Light	Weather Condition	Roadway	Near Intersection Roadway
6/25/2015	5:02 PM	Property damage only (none injured)	No injury	0	0	Head-on	V1: Travelling straight ahead / V2:Turning left	V1:N / V2:S	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires)		Dry	Daylight	Clear	SERVICE ROAD / AIRPORT STATION BUS ACCESS / COTTAGE STREET	
2/9/2015	6:50 AM	Property damage only (none injured)	No injury	0	0	Angle	V1: Travelling straight ahead / V2:Travelling straight ahead	V1:S / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires) V2:(Passenger car)		Snow	Daylight	Snow	SERVICE ROAD	AIRPORT STATION BUS ACCESS
6/1/2015	11:05 AM	Non-fatal injury	Non-fatal injury - Non-incapacitating	2	0	Angle	V1: Turning left / V2:Travelling straight ahead	V1:N / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic),(Collision with curb) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Bus (seats for more than 15 people, including driver))		Wet	Daylight	Rain	PRESCOTT STREET	FRANKFORT STREET
9/25/2016	3:19 PM	Property damage only (none injured)	No injury	0	0	Rear-end	V1: Slowing or stopped in traffic / V2:Slowing or stopped in traffic	V1:N / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:()	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Light truck(van, mini-van, panel, pickup, sport utility) with only four tires) V2:(Passenger car)		Dry	Daylight	Not Reported	FRANKFORT STREET / LOVELL STREET /	

Crash Date	Crash Time	Crash Severity	Maximum Injury Severity Reported	Number of NonFatal Injuries	Number of Fatal Injuries	Manner of Collision	Vehicle Action Prior to Crash	Vehicle Travel Directions	First Harmful Event	Most Harmful Events	Vehicle Sequence of Events	Vehicle Configuration	Non Motorist Type	Road Surface	Ambient Light	Weather Condition	Roadway	Near Intersection Roadway
6/1/2015	11:05 AM	Non-fatal injury	Non-fatal injury - Non-incapacitating	2	0	Angle	V1: Turning left / V2:Travelling straight ahead	V1:N / V2:N	Collision with motor vehicle in traffic	V1:(Collision with motor vehicle in traffic) V2:(Collision with motor vehicle in traffic)	V1:(Collision with motor vehicle in traffic),(Collision with curb) V2:(Collision with motor vehicle in traffic)	V1:(Passenger car) V2:(Bus (seats for more than 15 people, including driver))		Wet	Daylight	Rain	PRESCOTT STREET	FRANKFORT STREET

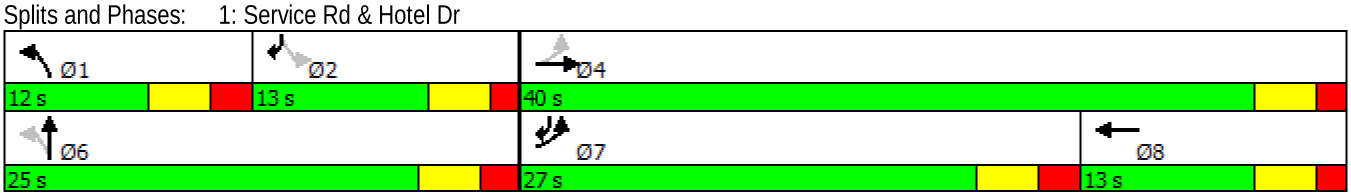
Intersection Analysis

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	180	115	0	0	125	5	110	110	50	40	0	145
Future Volume (vph)	180	115	0	0	125	5	110	110	50	40	0	145
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	125		0	0		0
Storage Lanes	1		0	0		0	1		0	1		1
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt					0.995			0.953				0.850
Flt Protected	0.950						0.950			0.950		
Satd. Flow (prot)	1770	1900	0	0	1890	0	1805	1811	0	1770	0	1583
Flt Permitted	0.366						0.950			0.649		
Satd. Flow (perm)	682	1900	0	0	1890	0	1805	1811	0	1209	0	1583
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)					2			37				161
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		419			173			305			324	
Travel Time (s)		9.5			3.9			6.9			7.4	
Peak Hour Factor	0.87	0.87	0.87	0.98	0.98	0.98	0.93	0.93	0.93	0.90	0.90	0.90
Heavy Vehicles (%)	2%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	2%
Adj. Flow (vph)	207	132	0	0	128	5	118	118	54	44	0	161
Shared Lane Traffic (%)												
Lane Group Flow (vph)	207	132	0	0	133	0	118	172	0	44	0	161
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		12			12			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	pm+pt	NA			NA		pm+pt	NA		Perm		pt+ov
Protected Phases	7	4			8		1	6				2 7
Permitted Phases	4						6			2		
Detector Phase	7	4			8		1	6		2		2 7
Switch Phase												
Minimum Initial (s)	5.0	5.0			5.0		5.0	5.0		5.5		
Minimum Split (s)	27.0	10.0			10.0		10.0	10.0		10.0		
Total Split (s)	27.0	40.0			13.0		12.0	25.0		13.0		
Total Split (%)	41.5%	61.5%			20.0%		18.5%	38.5%		20.0%		
Maximum Green (s)	22.0	35.5			8.5		7.0	20.0		8.5		
Yellow Time (s)	3.0	3.0			3.0		3.0	3.0		3.0		
All-Red Time (s)	2.0	1.5			1.5		2.0	2.0		1.5		
Lost Time Adjust (s)	0.0	0.0			0.0		0.0	0.0		0.0		
Total Lost Time (s)	5.0	4.5			4.5		5.0	5.0		4.5		
Lead/Lag	Lead				Lag		Lead			Lag		
Lead-Lag Optimize?	Yes				Yes		Yes			Yes		
Vehicle Extension (s)	3.0	3.0			3.0		3.0	3.0		3.0		
Recall Mode	None	None			None		None	Min		Min		

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Act Effct Green (s)	20.6	20.7			7.9		18.3	18.3		10.1		28.1
Actuated g/C Ratio	0.42	0.42			0.16		0.37	0.37		0.20		0.57
v/c Ratio	0.39	0.17			0.44		0.18	0.25		0.18		0.17
Control Delay	11.3	8.7			26.7		13.8	11.8		23.9		2.2
Queue Delay	0.0	0.0			0.0		0.0	0.0		0.0		0.0
Total Delay	11.3	8.7			26.7		13.8	11.8		23.9		2.2
LOS	B	A			C		B	B		C		A
Approach Delay		10.3			26.7			12.6			6.9	
Approach LOS		B			C			B			A	
Queue Length 50th (ft)	37	22			38		25	29		13		0
Queue Length 95th (ft)	70	46			90		61	73		40		23
Internal Link Dist (ft)		339			93			225			244	
Turn Bay Length (ft)							125					
Base Capacity (vph)	869	1377			346		667	798		264		1118
Starvation Cap Reductn	0	0			0		0	0		0		0
Spillback Cap Reductn	0	0			0		0	0		0		0
Storage Cap Reductn	0	0			0		0	0		0		0
Reduced v/c Ratio	0.24	0.10			0.38		0.18	0.22		0.17		0.14

Intersection Summary	
Area Type: Other	
Cycle Length: 65	
Actuated Cycle Length: 49.5	
Natural Cycle: 60	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.44	
Intersection Signal Delay: 12.5	Intersection LOS: B
Intersection Capacity Utilization 44.0%	ICU Level of Service A
Analysis Period (min) 15	

Splits and Phases: 1: Service Rd & Hotel Dr



Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	15	0	0	0	0	0	30	270	0	0	165	55
Future Volume (vph)	15	0	0	0	0	0	30	270	0	0	165	55
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.95	0.95	0.95	0.95	0.95
Frt											0.962	
Flt Protected		0.950						0.995				
Satd. Flow (prot)	0	1770	0	0	1863	0	0	3522	0	0	3405	0
Flt Permitted								0.915				
Satd. Flow (perm)	0	1863	0	0	1863	0	0	3238	0	0	3405	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)											60	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		216			223			107			200	
Travel Time (s)		4.9			5.1			2.4			4.5	
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Adj. Flow (vph)	16	0	0	0	0	0	33	293	0	0	179	60
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	16	0	0	0	0	0	326	0	0	239	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			0			0	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	Perm	NA					Perm	NA			NA	
Protected Phases		4			8			2			6	
Permitted Phases	4			8			2			6		
Detector Phase	4	4		8	8		2	2		6	6	
Switch Phase												
Minimum Initial (s)	5.0	5.0		5.0	5.0		10.0	10.0		10.0	10.0	
Minimum Split (s)	22.5	22.5		22.5	22.5		23.0	23.0		35.5	35.5	
Total Split (s)	23.0	23.0		23.0	23.0		30.0	30.0		42.0	42.0	
Total Split (%)	35.4%	35.4%		35.4%	35.4%		46.2%	46.2%		64.6%	64.6%	
Maximum Green (s)	18.5	18.5		18.5	18.5		25.0	25.0		36.5	36.5	
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		2.0	2.0		2.5	2.5	
Lost Time Adjust (s)		0.0			0.0			0.0			0.0	
Total Lost Time (s)		4.5			4.5			5.0			5.5	
Lead/Lag							Lag	Lag				
Lead-Lag Optimize?							Yes	Yes				
Vehicle Extension (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
Recall Mode	None	None		None	None		Min	Min		Min	Min	
Walk Time (s)										7.0	7.0	
Flash Dont Walk (s)										23.0	23.0	
Pedestrian Calls (#/hr)										8	8	
Act Effct Green (s)		6.2						28.7			30.2	

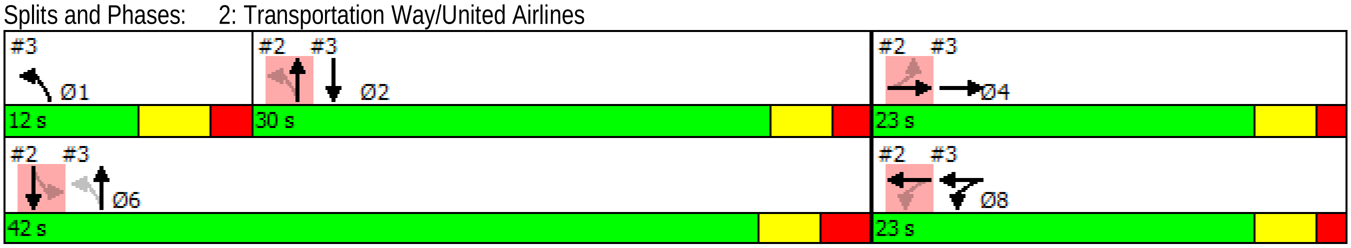
Lane Group	Ø1
Lane Configurations	
Traffic Volume (vph)	
Future Volume (vph)	
Ideal Flow (vphpl)	
Lane Util. Factor	
Frt	
Flt Protected	
Satd. Flow (prot)	
Flt Permitted	
Satd. Flow (perm)	
Right Turn on Red	
Satd. Flow (RTOR)	
Link Speed (mph)	
Link Distance (ft)	
Travel Time (s)	
Peak Hour Factor	
Adj. Flow (vph)	
Shared Lane Traffic (%)	
Lane Group Flow (vph)	
Enter Blocked Intersection	
Lane Alignment	
Median Width(ft)	
Link Offset(ft)	
Crosswalk Width(ft)	
Two way Left Turn Lane	
Headway Factor	
Turning Speed (mph)	
Turn Type	
Protected Phases	1
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	5.0
Minimum Split (s)	10.5
Total Split (s)	12.0
Total Split (%)	18%
Maximum Green (s)	6.5
Yellow Time (s)	3.5
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	Lead
Lead-Lag Optimize?	Yes
Vehicle Extension (s)	3.0
Recall Mode	None
Walk Time (s)	
Flash Dont Walk (s)	
Pedestrian Calls (#/hr)	
Act Effct Green (s)	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Actuated g/C Ratio		0.19						0.88			0.93	
v/c Ratio		0.05						0.11			0.08	
Control Delay		13.3						3.4			0.5	
Queue Delay		0.0						0.0			0.0	
Total Delay		13.3						3.4			0.5	
LOS		B						A			A	
Approach Delay		13.3						3.4			0.5	
Approach LOS		B						A			A	
Queue Length 50th (ft)		2						0			0	
Queue Length 95th (ft)		16						51			0	
Internal Link Dist (ft)		136			143			27			120	
Turn Bay Length (ft)												
Base Capacity (vph)		1110						2933			3253	
Starvation Cap Reductn		0						0			407	
Spillback Cap Reductn		0						0			0	
Storage Cap Reductn		0						0			0	
Reduced v/c Ratio		0.01						0.11			0.08	

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 32.6
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.16
Intersection Signal Delay: 2.5 Intersection LOS: A
Intersection Capacity Utilization 33.3% ICU Level of Service A
Analysis Period (min) 15

Splits and Phases: 2: Transportation Way/United Airlines



Lane Group	Ø1
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	
Queue Length 50th (ft)	
Queue Length 95th (ft)	
Internal Link Dist (ft)	
Turn Bay Length (ft)	
Base Capacity (vph)	
Starvation Cap Reductn	
Spillback Cap Reductn	
Storage Cap Reductn	
Reduced v/c Ratio	

Intersection Summary

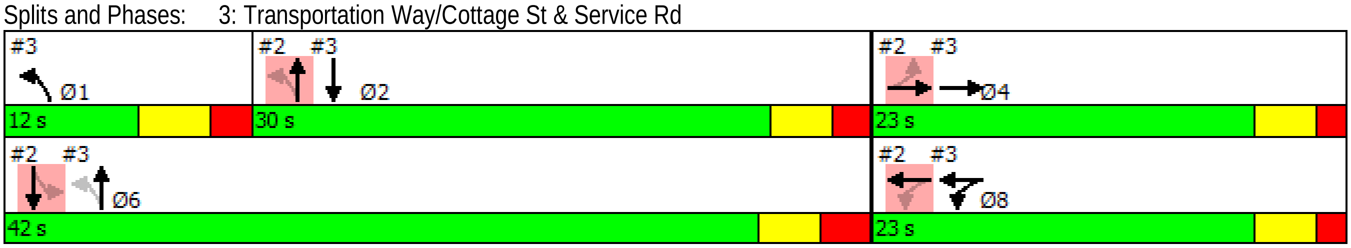
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	0	5	0	5	0	5	20	255	10	0	215	5
Future Volume (vph)	0	5	0	5	0	5	20	255	10	0	215	5
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	0		0	0		165
Storage Lanes	0		0	0		0	1		0	0		0
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt					0.932			0.994			0.997	
Flt Protected					0.976		0.950					
Satd. Flow (prot)	0	1863	0	0	1728	0	1805	1853	0	0	1858	0
Flt Permitted					0.976		0.495					
Satd. Flow (perm)	0	1863	0	0	1728	0	940	1853	0	0	1858	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)					134			5			2	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		165			431			200			383	
Travel Time (s)		3.8			9.8			4.5			8.7	
Peak Hour Factor	0.92	0.92	0.92	0.50	0.50	0.50	0.94	0.94	0.94	0.92	0.92	0.92
Heavy Vehicles (%)	2%	2%	2%	0%	0%	0%	0%	2%	0%	0%	2%	0%
Adj. Flow (vph)	0	5	0	10	0	10	21	271	11	0	234	5
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	5	0	0	20	0	21	282	0	0	239	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type		NA		Split	NA		pm+pt	NA			NA	
Protected Phases		4!		8!	8		1	6			2	
Permitted Phases							6					
Detector Phase		4		8	8		1	6			2	
Switch Phase												
Minimum Initial (s)		5.0		5.0	5.0		5.0	10.0			10.0	
Minimum Split (s)		22.5		22.5	22.5		10.5	35.5			23.0	
Total Split (s)		23.0		23.0	23.0		12.0	42.0			30.0	
Total Split (%)		35.4%		35.4%	35.4%		18.5%	64.6%			46.2%	
Maximum Green (s)		18.5		18.5	18.5		6.5	36.5			25.0	
Yellow Time (s)		3.0		3.0	3.0		3.5	3.0			3.0	
All-Red Time (s)		1.5		1.5	1.5		2.0	2.5			2.0	
Lost Time Adjust (s)		0.0			0.0		0.0	0.0			0.0	
Total Lost Time (s)		4.5			4.5		5.5	5.5			5.0	
Lead/Lag							Lead				Lag	
Lead-Lag Optimize?							Yes				Yes	
Vehicle Extension (s)		3.0		3.0	3.0		3.0	3.0			3.0	
Recall Mode		None		None	None		None	Min			Min	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Walk Time (s)								7.0				
Flash Dont Walk (s)								23.0				
Pedestrian Calls (#/hr)								8				
Act Effct Green (s)		6.2			6.0		25.2	30.2			28.7	
Actuated g/C Ratio		0.19			0.18		0.77	0.93			0.88	
v/c Ratio		0.01			0.05		0.02	0.16			0.15	
Control Delay		13.4			0.2		1.3	1.2			4.0	
Queue Delay		0.0			0.0		0.0	0.0			0.0	
Total Delay		13.4			0.2		1.3	1.2			4.0	
LOS		B			A		A	A			A	
Approach Delay		13.4			0.2			1.2			4.0	
Approach LOS		B			A			A			A	
Queue Length 50th (ft)		1			0		1	0			0	
Queue Length 95th (ft)		8			0		4	22			82	
Internal Link Dist (ft)		85			351			120			303	
Turn Bay Length (ft)												
Base Capacity (vph)		1110			1083		907	1769			1683	
Starvation Cap Reductn		0			0		0	155			0	
Spillback Cap Reductn		0			0		0	0			0	
Storage Cap Reductn		0			0		0	0			0	
Reduced v/c Ratio		0.00			0.02		0.02	0.17			0.14	

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 32.6
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.16
Intersection Signal Delay: 2.4 Intersection LOS: A
Intersection Capacity Utilization 30.1% ICU Level of Service A
Analysis Period (min) 15
! Phase conflict between lane groups.

Splits and Phases: 3: Transportation Way/Cottage St & Service Rd



Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (vph)	35	35	155	100	45	185
Future Volume (vph)	35	35	155	100	45	185
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0	235		0	0	
Storage Lanes	1	1		0	0	
Taper Length (ft)	25				25	
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00
Frt		0.850	0.947			
Flt Protected	0.950					0.990
Satd. Flow (prot)	1752	1417	1768	0	0	1809
Flt Permitted	0.950					0.990
Satd. Flow (perm)	1752	1417	1768	0	0	1809
Link Speed (mph)	30		30			30
Link Distance (ft)	1123		576			417
Travel Time (s)	25.5		13.1			9.5
Peak Hour Factor	0.87	0.87	0.95	0.95	0.89	0.89
Heavy Vehicles (%)	3%	14%	1%	3%	12%	2%
Adj. Flow (vph)	40	40	163	105	51	208
Shared Lane Traffic (%)						
Lane Group Flow (vph)	40	40	268	0	0	259
Enter Blocked Intersection	No	No	No	No	No	No
Lane Alignment	Left	Right	Left	Right	Left	Left
Median Width(ft)	12		0			0
Link Offset(ft)	0		0			0
Crosswalk Width(ft)	16		16			16
Two way Left Turn Lane						
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15	9		9	15	
Sign Control	Stop		Free			Free

Intersection Summary

Area Type: Other

Control Type: Unsignalized

Intersection Capacity Utilization 39.8% ICU Level of Service A

Analysis Period (min) 15

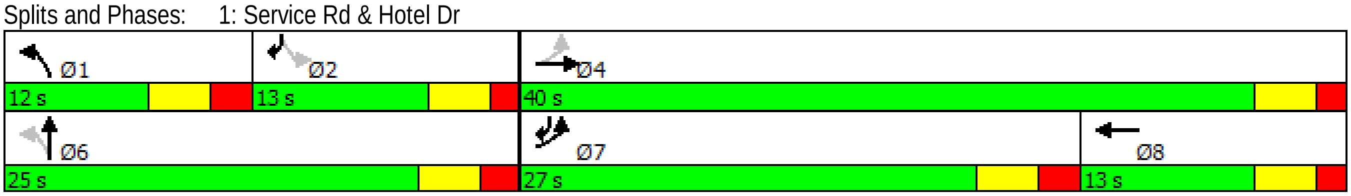
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	205	130	0	0	50	10	30	160	15	95	0	135
Future Volume (vph)	205	130	0	0	50	10	30	160	15	95	0	135
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	125		0	0		0
Storage Lanes	1		0	0		0	1		0	1		1
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt					0.978			0.987				0.850
Flt Protected	0.950						0.950			0.950		
Satd. Flow (prot)	1770	1900	0	0	1858	0	1805	1875	0	1770	0	1583
Flt Permitted	0.556						0.950			0.639		
Satd. Flow (perm)	1036	1900	0	0	1858	0	1805	1875	0	1190	0	1583
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)					10			7				150
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		419			173			305			324	
Travel Time (s)		9.5			3.9			6.9			7.4	
Peak Hour Factor	0.87	0.87	0.87	0.98	0.98	0.98	0.93	0.93	0.93	0.90	0.90	0.90
Heavy Vehicles (%)	2%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	2%
Adj. Flow (vph)	236	149	0	0	51	10	32	172	16	106	0	150
Shared Lane Traffic (%)												
Lane Group Flow (vph)	236	149	0	0	61	0	32	188	0	106	0	150
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		12			12			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	pm+pt	NA			NA		pm+pt	NA		Perm		pt+ov
Protected Phases	7	4			8		1	6				2 7
Permitted Phases	4						6			2		
Detector Phase	7	4			8		1	6		2		2 7
Switch Phase												
Minimum Initial (s)	5.0	5.0			5.0		5.0	5.0		5.5		
Minimum Split (s)	27.0	10.0			10.0		10.0	10.0		10.0		
Total Split (s)	27.0	40.0			13.0		12.0	25.0		13.0		
Total Split (%)	41.5%	61.5%			20.0%		18.5%	38.5%		20.0%		
Maximum Green (s)	22.0	35.5			8.5		7.0	20.0		8.5		
Yellow Time (s)	3.0	3.0			3.0		3.0	3.0		3.0		
All-Red Time (s)	2.0	1.5			1.5		2.0	2.0		1.5		
Lost Time Adjust (s)	0.0	0.0			0.0		0.0	0.0		0.0		
Total Lost Time (s)	5.0	4.5			4.5		5.0	5.0		4.5		
Lead/Lag	Lead				Lag		Lead			Lag		
Lead-Lag Optimize?	Yes				Yes		Yes			Yes		
Vehicle Extension (s)	3.0	3.0			3.0		3.0	3.0		3.0		
Recall Mode	None	None			None		None	Min		Min		

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Act Effct Green (s)	15.2	14.9			7.3		13.6	13.6		11.0		32.4
Actuated g/C Ratio	0.38	0.37			0.18		0.34	0.34		0.27		0.80
v/c Ratio	0.39	0.21			0.18		0.05	0.29		0.33		0.12
Control Delay	10.3	8.4			18.6		12.5	13.2		24.8		2.0
Queue Delay	0.0	0.0			0.0		0.0	0.0		0.0		0.0
Total Delay	10.3	8.4			18.6		12.5	13.2		24.8		2.0
LOS	B	A			B		B	B		C		A
Approach Delay		9.6			18.6			13.1			11.5	
Approach LOS		A			B			B			B	
Queue Length 50th (ft)	25	14			6		3	21		11		0
Queue Length 95th (ft)	79	50			47		24	93		#102		22
Internal Link Dist (ft)		339			93			225			244	
Turn Bay Length (ft)							125					
Base Capacity (vph)	1153	1601			455		612	1067		334		1332
Starvation Cap Reductn	0	0			0		0	0		0		0
Spillback Cap Reductn	0	0			0		0	0		0		0
Storage Cap Reductn	0	0			0		0	0		0		0
Reduced v/c Ratio	0.20	0.09			0.13		0.05	0.18		0.32		0.11

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 40.3
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.39
Intersection Signal Delay: 11.5 Intersection LOS: B
Intersection Capacity Utilization 43.9% ICU Level of Service A
Analysis Period (min) 15
\# 95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1: Service Rd & Hotel Dr



Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	15	0	0	0	0	0	30	270	0	0	165	55
Future Volume (vph)	15	0	0	0	0	0	30	270	0	0	165	55
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.95	0.95	0.95	0.95	0.95
Frt											0.962	
Flt Protected		0.950						0.995				
Satd. Flow (prot)	0	1770	0	0	1863	0	0	3522	0	0	3405	0
Flt Permitted		0.950						0.915				
Satd. Flow (perm)	0	1770	0	0	1863	0	0	3238	0	0	3405	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)											60	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		216			223			107			200	
Travel Time (s)		4.9			5.1			2.4			4.5	
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Adj. Flow (vph)	16	0	0	0	0	0	33	293	0	0	179	60
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	16	0	0	0	0	0	326	0	0	239	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			0			0	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	Perm	NA					Perm	NA			NA	
Protected Phases		4			8			2			6	
Permitted Phases	4			8			2			6		
Detector Phase	4	4		8	8		2	2		6	6	
Switch Phase												
Minimum Initial (s)	5.0	5.0		5.0	5.0		10.0	10.0		10.0	10.0	
Minimum Split (s)	22.5	22.5		22.5	22.5		23.0	23.0		35.5	35.5	
Total Split (s)	23.0	23.0		23.0	23.0		30.0	30.0		42.0	42.0	
Total Split (%)	35.4%	35.4%		35.4%	35.4%		46.2%	46.2%		64.6%	64.6%	
Maximum Green (s)	18.5	18.5		18.5	18.5		25.0	25.0		36.5	36.5	
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		2.0	2.0		2.5	2.5	
Lost Time Adjust (s)		0.0			0.0			0.0			0.0	
Total Lost Time (s)		4.5			4.5			5.0			5.5	
Lead/Lag							Lag	Lag				
Lead-Lag Optimize?							Yes	Yes				
Vehicle Extension (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
Recall Mode	None	None		None	None		Min	Min		Min	Min	
Walk Time (s)										7.0	7.0	
Flash Dont Walk (s)										23.0	23.0	
Pedestrian Calls (#/hr)										8	8	
Act Effct Green (s)		6.3						31.5			33.0	

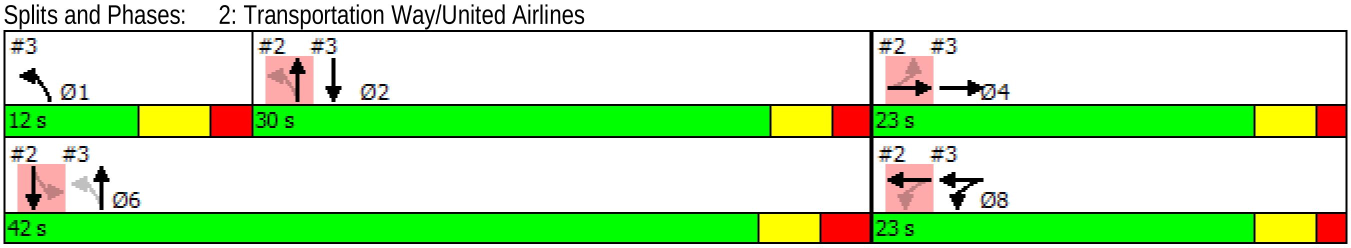
Lane Group	Ø1
Lane Configurations	
Traffic Volume (vph)	
Future Volume (vph)	
Ideal Flow (vphpl)	
Lane Util. Factor	
Frt	
Flt Protected	
Satd. Flow (prot)	
Flt Permitted	
Satd. Flow (perm)	
Right Turn on Red	
Satd. Flow (RTOR)	
Link Speed (mph)	
Link Distance (ft)	
Travel Time (s)	
Peak Hour Factor	
Adj. Flow (vph)	
Shared Lane Traffic (%)	
Lane Group Flow (vph)	
Enter Blocked Intersection	
Lane Alignment	
Median Width(ft)	
Link Offset(ft)	
Crosswalk Width(ft)	
Two way Left Turn Lane	
Headway Factor	
Turning Speed (mph)	
Turn Type	
Protected Phases	1
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	5.0
Minimum Split (s)	10.5
Total Split (s)	12.0
Total Split (%)	18%
Maximum Green (s)	6.5
Yellow Time (s)	3.5
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	Lead
Lead-Lag Optimize?	Yes
Vehicle Extension (s)	3.0
Recall Mode	None
Walk Time (s)	
Flash Dont Walk (s)	
Pedestrian Calls (#/hr)	
Act Effct Green (s)	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Actuated g/C Ratio		0.18						0.89			0.93	
v/c Ratio		0.05						0.11			0.07	
Control Delay		15.9						3.0			0.4	
Queue Delay		0.0						0.0			0.0	
Total Delay		15.9						3.0			0.4	
LOS		B						A			A	
Approach Delay		15.9						3.0			0.4	
Approach LOS		B						A			A	
Queue Length 50th (ft)		2						0			0	
Queue Length 95th (ft)		18						50			0	
Internal Link Dist (ft)		136			143			27			120	
Turn Bay Length (ft)												
Base Capacity (vph)		975						2893			3193	
Starvation Cap Reductn		0						0			449	
Spillback Cap Reductn		0						0			0	
Storage Cap Reductn		0						0			0	
Reduced v/c Ratio		0.02						0.11			0.09	

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 35.3
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.24
Intersection Signal Delay: 2.3 Intersection LOS: A
Intersection Capacity Utilization 33.3% ICU Level of Service A
Analysis Period (min) 15

Splits and Phases: 2: Transportation Way/United Airlines



Lane Group	Ø1
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	
Queue Length 50th (ft)	
Queue Length 95th (ft)	
Internal Link Dist (ft)	
Turn Bay Length (ft)	
Base Capacity (vph)	
Starvation Cap Reductn	
Spillback Cap Reductn	
Storage Cap Reductn	
Reduced v/c Ratio	

Intersection Summary

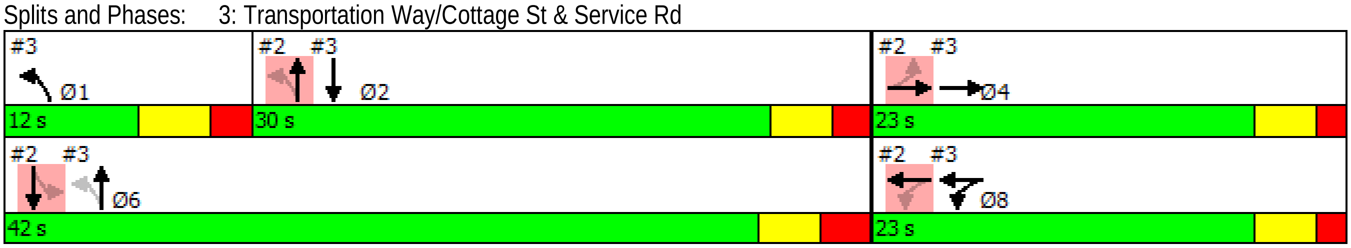
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	0	0	2	0	0	0	20	305	10	0	360	5
Future Volume (vph)	0	0	2	0	0	0	20	305	10	0	360	5
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	0		0	0		165
Storage Lanes	0		0	0		0	1		0	0		0
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt		0.865						0.995			0.998	
Flt Protected							0.950					
Satd. Flow (prot)	0	1611	0	0	1900	0	1805	1855	0	0	1859	0
Flt Permitted							0.437					
Satd. Flow (perm)	0	1611	0	0	1900	0	830	1855	0	0	1859	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)		459						4			1	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		165			431			200			383	
Travel Time (s)		3.8			9.8			4.5			8.7	
Peak Hour Factor	0.92	0.92	0.92	0.50	0.50	0.50	0.94	0.94	0.94	0.92	0.92	0.92
Heavy Vehicles (%)	2%	2%	2%	0%	0%	0%	0%	2%	0%	0%	2%	0%
Adj. Flow (vph)	0	0	2	0	0	0	21	324	11	0	391	5
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	2	0	0	0	0	21	335	0	0	396	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type		NA					pm+pt	NA			NA	
Protected Phases		4!		8!	8		1	6			2	
Permitted Phases							6					
Detector Phase		4		8	8		1	6			2	
Switch Phase												
Minimum Initial (s)		5.0		5.0	5.0		5.0	10.0			10.0	
Minimum Split (s)		22.5		22.5	22.5		10.5	35.5			23.0	
Total Split (s)		23.0		23.0	23.0		12.0	42.0			30.0	
Total Split (%)		35.4%		35.4%	35.4%		18.5%	64.6%			46.2%	
Maximum Green (s)		18.5		18.5	18.5		6.5	36.5			25.0	
Yellow Time (s)		3.0		3.0	3.0		3.5	3.0			3.0	
All-Red Time (s)		1.5		1.5	1.5		2.0	2.5			2.0	
Lost Time Adjust (s)		0.0			0.0		0.0	0.0			0.0	
Total Lost Time (s)		4.5			4.5		5.5	5.5			5.0	
Lead/Lag							Lead				Lag	
Lead-Lag Optimize?							Yes				Yes	
Vehicle Extension (s)		3.0		3.0	3.0		3.0	3.0			3.0	
Recall Mode		None		None	None		None	Min			Min	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Walk Time (s)								7.0				
Flash Dont Walk (s)								23.0				
Pedestrian Calls (#/hr)								8				
Act Effct Green (s)		6.3					27.9	33.0			31.5	
Actuated g/C Ratio		0.18					0.79	0.93			0.89	
v/c Ratio		0.00					0.03	0.19			0.24	
Control Delay		0.0					1.2	1.1			3.8	
Queue Delay		0.0					0.0	0.0			0.0	
Total Delay		0.0					1.2	1.2			3.8	
LOS		A					A	A			A	
Approach Delay								1.2			3.8	
Approach LOS								A			A	
Queue Length 50th (ft)		0					1	1			0	
Queue Length 95th (ft)		0					4	29			138	
Internal Link Dist (ft)		85			351			120			303	
Turn Bay Length (ft)												
Base Capacity (vph)		1093					846	1738			1661	
Starvation Cap Reductn		0					0	167			0	
Spillback Cap Reductn		0					0	0			0	
Storage Cap Reductn		0					0	0			0	
Reduced v/c Ratio		0.00					0.02	0.21			0.24	

Intersection Summary	
Area Type: Other	
Cycle Length: 65	
Actuated Cycle Length: 35.3	
Natural Cycle: 60	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.24	
Intersection Signal Delay: 2.6	Intersection LOS: A
Intersection Capacity Utilization 31.3%	ICU Level of Service A
Analysis Period (min) 15	

! Phase conflict between lane groups.

Splits and Phases: 3: Transportation Way/Cottage St & Service Rd



Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (vph)	65	55	175	130	45	300
Future Volume (vph)	65	55	175	130	45	300
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0	235		0	0	
Storage Lanes	1	1		0	0	
Taper Length (ft)	25				25	
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00
Frt		0.850	0.942			
Flt Protected	0.950					0.993
Satd. Flow (prot)	1752	1417	1757	0	0	1826
Flt Permitted	0.950					0.993
Satd. Flow (perm)	1752	1417	1757	0	0	1826
Link Speed (mph)	30		30			30
Link Distance (ft)	1123		576			417
Travel Time (s)	25.5		13.1			9.5
Peak Hour Factor	0.87	0.87	0.95	0.95	0.89	0.89
Heavy Vehicles (%)	3%	14%	1%	3%	12%	2%
Adj. Flow (vph)	75	63	184	137	51	337
Shared Lane Traffic (%)						
Lane Group Flow (vph)	75	63	321	0	0	388
Enter Blocked Intersection	No	No	No	No	No	No
Lane Alignment	Left	Right	Left	Right	Left	Left
Median Width(ft)	12		0			0
Link Offset(ft)	0		0			0
Crosswalk Width(ft)	16		16			16
Two way Left Turn Lane						
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15	9		9	15	
Sign Control	Stop		Free			Free

Intersection Summary

Area Type: Other
Control Type: Unsignalized
Intersection Capacity Utilization 49.0% ICU Level of Service A
Analysis Period (min) 15

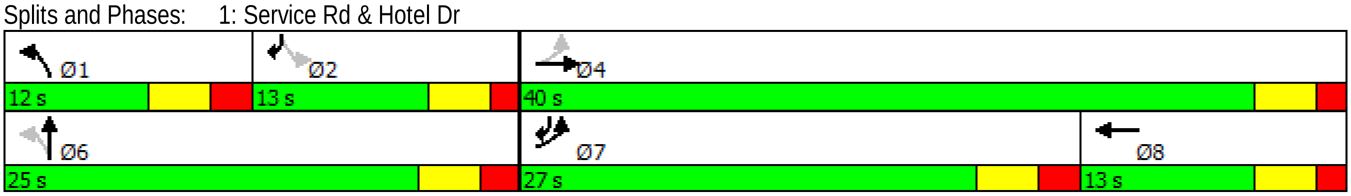
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	250	130	0	0	50	10	30	160	15	110	0	135
Future Volume (vph)	250	130	0	0	50	10	30	160	15	110	0	135
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	125		0	0		0
Storage Lanes	1		0	0		0	1		0	1		1
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt					0.978			0.987				0.850
Flt Protected	0.950						0.950			0.950		
Satd. Flow (prot)	1770	1900	0	0	1858	0	1805	1875	0	1770	0	1583
Flt Permitted	0.556						0.950			0.639		
Satd. Flow (perm)	1036	1900	0	0	1858	0	1805	1875	0	1190	0	1583
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)					10			7				150
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		419			173			305			324	
Travel Time (s)		9.5			3.9			6.9			7.4	
Peak Hour Factor	0.87	0.87	0.87	0.98	0.98	0.98	0.93	0.93	0.93	0.90	0.90	0.90
Heavy Vehicles (%)	2%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	2%
Adj. Flow (vph)	287	149	0	0	51	10	32	172	16	122	0	150
Shared Lane Traffic (%)												
Lane Group Flow (vph)	287	149	0	0	61	0	32	188	0	122	0	150
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		12			12			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	pm+pt	NA			NA		pm+pt	NA		Perm		pt+ov
Protected Phases	7	4			8		1	6				2 7
Permitted Phases	4						6			2		
Detector Phase	7	4			8		1	6		2		2 7
Switch Phase												
Minimum Initial (s)	5.0	5.0			5.0		5.0	5.0		5.5		
Minimum Split (s)	27.0	10.0			10.0		10.0	10.0		10.0		
Total Split (s)	27.0	40.0			13.0		12.0	25.0		13.0		
Total Split (%)	41.5%	61.5%			20.0%		18.5%	38.5%		20.0%		
Maximum Green (s)	22.0	35.5			8.5		7.0	20.0		8.5		
Yellow Time (s)	3.0	3.0			3.0		3.0	3.0		3.0		
All-Red Time (s)	2.0	1.5			1.5		2.0	2.0		1.5		
Lost Time Adjust (s)	0.0	0.0			0.0		0.0	0.0		0.0		
Total Lost Time (s)	5.0	4.5			4.5		5.0	5.0		4.5		
Lead/Lag	Lead				Lag		Lead			Lag		
Lead-Lag Optimize?	Yes				Yes		Yes			Yes		
Vehicle Extension (s)	3.0	3.0			3.0		3.0	3.0		3.0		
Recall Mode	None	None			None		None	Min		Min		

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Act Effct Green (s)	16.7	16.0			7.4		13.2	13.2		10.6		33.7
Actuated g/C Ratio	0.40	0.39			0.18		0.32	0.32		0.26		0.81
v/c Ratio	0.44	0.20			0.18		0.06	0.31		0.40		0.11
Control Delay	10.5	8.1			19.8		13.9	14.5		28.4		1.9
Queue Delay	0.0	0.0			0.0		0.0	0.0		0.0		0.0
Total Delay	10.5	8.1			19.8		13.9	14.5		28.4		1.9
LOS	B	A			B		B	B		C		A
Approach Delay		9.7			19.8			14.4			13.8	
Approach LOS		A			B			B			B	
Queue Length 50th (ft)	31	14			7		4	22		15		0
Queue Length 95th (ft)	95	49			49		26	102		#130		21
Internal Link Dist (ft)		339			93			225			244	
Turn Bay Length (ft)							125					
Base Capacity (vph)	1155	1578			449		573	1051		303		1252
Starvation Cap Reductn	0	0			0		0	0		0		0
Spillback Cap Reductn	0	0			0		0	0		0		0
Storage Cap Reductn	0	0			0		0	0		0		0
Reduced v/c Ratio	0.25	0.09			0.14		0.06	0.18		0.40		0.12

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 41.5
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.44
Intersection Signal Delay: 12.5	Intersection LOS: B
Intersection Capacity Utilization 47.2%	ICU Level of Service A
Analysis Period (min) 15
95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1: Service Rd & Hotel Dr



Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	15	0	0	0	0	0	30	270	0	0	165	55
Future Volume (vph)	15	0	0	0	0	0	30	270	0	0	165	55
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.95	0.95	0.95	0.95	0.95
Frt											0.962	
Flt Protected		0.950						0.995				
Satd. Flow (prot)	0	1770	0	0	1863	0	0	3522	0	0	3405	0
Flt Permitted		0.950						0.915				
Satd. Flow (perm)	0	1770	0	0	1863	0	0	3238	0	0	3405	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)											60	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		216			223			107			200	
Travel Time (s)		4.9			5.1			2.4			4.5	
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Adj. Flow (vph)	16	0	0	0	0	0	33	293	0	0	179	60
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	16	0	0	0	0	0	326	0	0	239	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			0			0	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	Perm	NA					Perm	NA			NA	
Protected Phases		4			8			2			6	
Permitted Phases	4			8			2			6		
Detector Phase	4	4		8	8		2	2		6	6	
Switch Phase												
Minimum Initial (s)	5.0	5.0		5.0	5.0		10.0	10.0		10.0	10.0	
Minimum Split (s)	22.5	22.5		22.5	22.5		23.0	23.0		35.5	35.5	
Total Split (s)	23.0	23.0		23.0	23.0		30.0	30.0		42.0	42.0	
Total Split (%)	35.4%	35.4%		35.4%	35.4%		46.2%	46.2%		64.6%	64.6%	
Maximum Green (s)	18.5	18.5		18.5	18.5		25.0	25.0		36.5	36.5	
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		2.0	2.0		2.5	2.5	
Lost Time Adjust (s)		0.0			0.0			0.0			0.0	
Total Lost Time (s)		4.5			4.5			5.0			5.5	
Lead/Lag							Lag	Lag				
Lead-Lag Optimize?							Yes	Yes				
Vehicle Extension (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
Recall Mode	None	None		None	None		Min	Min		Min	Min	
Walk Time (s)										7.0	7.0	
Flash Dont Walk (s)										23.0	23.0	
Pedestrian Calls (#/hr)										8	8	
Act Effct Green (s)		6.1						29.7			31.3	

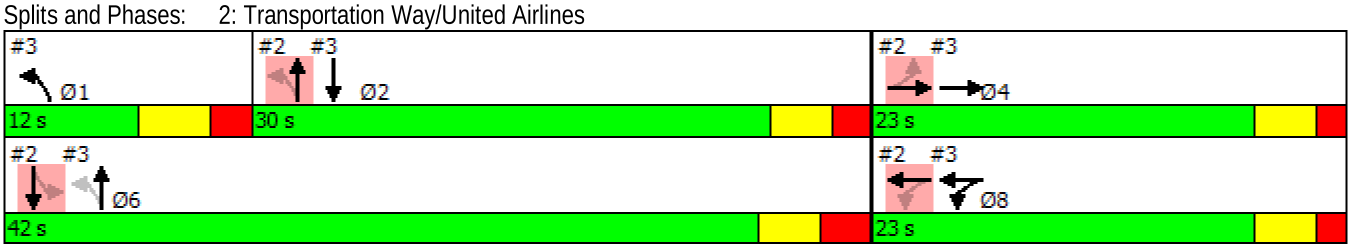
Lane Group	Ø1
Lane Configurations	
Traffic Volume (vph)	
Future Volume (vph)	
Ideal Flow (vphpl)	
Lane Util. Factor	
Frt	
Flt Protected	
Satd. Flow (prot)	
Flt Permitted	
Satd. Flow (perm)	
Right Turn on Red	
Satd. Flow (RTOR)	
Link Speed (mph)	
Link Distance (ft)	
Travel Time (s)	
Peak Hour Factor	
Adj. Flow (vph)	
Shared Lane Traffic (%)	
Lane Group Flow (vph)	
Enter Blocked Intersection	
Lane Alignment	
Median Width(ft)	
Link Offset(ft)	
Crosswalk Width(ft)	
Two way Left Turn Lane	
Headway Factor	
Turning Speed (mph)	
Turn Type	
Protected Phases	1
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	5.0
Minimum Split (s)	10.5
Total Split (s)	12.0
Total Split (%)	18%
Maximum Green (s)	6.5
Yellow Time (s)	3.5
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	Lead
Lead-Lag Optimize?	Yes
Vehicle Extension (s)	3.0
Recall Mode	None
Walk Time (s)	
Flash Dont Walk (s)	
Pedestrian Calls (#/hr)	
Act Effct Green (s)	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Actuated g/C Ratio		0.18						0.88			0.93	
v/c Ratio		0.05						0.11			0.08	
Control Delay		14.3						3.4			0.5	
Queue Delay		0.0						0.0			0.0	
Total Delay		14.3						3.4			0.5	
LOS		B						A			A	
Approach Delay		14.3						3.4			0.5	
Approach LOS		B						A			A	
Queue Length 50th (ft)		2						0			0	
Queue Length 95th (ft)		16						51			0	
Internal Link Dist (ft)		136			143			27			120	
Turn Bay Length (ft)												
Base Capacity (vph)		997						2933			3253	
Starvation Cap Reductn		0						0			405	
Spillback Cap Reductn		0						0			0	
Storage Cap Reductn		0						0			0	
Reduced v/c Ratio		0.02						0.11			0.08	

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 33.8
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.16
Intersection Signal Delay: 2.5 Intersection LOS: A
Intersection Capacity Utilization 33.3% ICU Level of Service A
Analysis Period (min) 15

Splits and Phases: 2: Transportation Way/United Airlines



Lane Group	Ø1
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	
Queue Length 50th (ft)	
Queue Length 95th (ft)	
Internal Link Dist (ft)	
Turn Bay Length (ft)	
Base Capacity (vph)	
Starvation Cap Reductn	
Spillback Cap Reductn	
Storage Cap Reductn	
Reduced v/c Ratio	

Intersection Summary

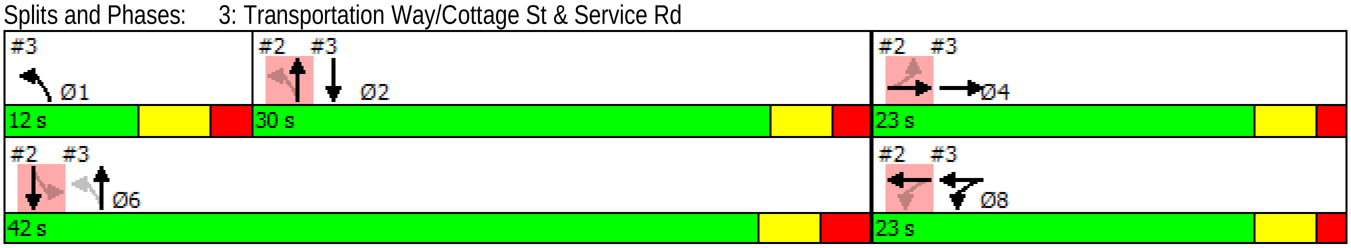
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	0	0	2	0	0	0	20	255	10	0	215	5
Future Volume (vph)	0	0	2	0	0	0	20	255	10	0	215	5
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	0		0	0		165
Storage Lanes	0		0	0		0	1		0	0		0
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt		0.865						0.994			0.997	
Flt Protected							0.950					
Satd. Flow (prot)	0	1611	0	0	1900	0	1805	1853	0	0	1858	0
Flt Permitted							0.499					
Satd. Flow (perm)	0	1611	0	0	1900	0	948	1853	0	0	1858	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)		623						5			2	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		165			431			200			383	
Travel Time (s)		3.8			9.8			4.5			8.7	
Peak Hour Factor	0.92	0.92	0.92	0.50	0.50	0.50	0.94	0.94	0.94	0.92	0.92	0.92
Heavy Vehicles (%)	2%	2%	2%	0%	0%	0%	0%	2%	0%	0%	2%	0%
Adj. Flow (vph)	0	0	2	0	0	0	21	271	11	0	234	5
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	2	0	0	0	0	21	282	0	0	239	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type		NA					pm+pt	NA			NA	
Protected Phases		4!		8!	8		1	6			2	
Permitted Phases							6					
Detector Phase		4		8	8		1	6			2	
Switch Phase												
Minimum Initial (s)		5.0		5.0	5.0		5.0	10.0			10.0	
Minimum Split (s)		22.5		22.5	22.5		10.5	35.5			23.0	
Total Split (s)		23.0		23.0	23.0		12.0	42.0			30.0	
Total Split (%)		35.4%		35.4%	35.4%		18.5%	64.6%			46.2%	
Maximum Green (s)		18.5		18.5	18.5		6.5	36.5			25.0	
Yellow Time (s)		3.0		3.0	3.0		3.5	3.0			3.0	
All-Red Time (s)		1.5		1.5	1.5		2.0	2.5			2.0	
Lost Time Adjust (s)		0.0			0.0		0.0	0.0			0.0	
Total Lost Time (s)		4.5			4.5		5.5	5.5			5.0	
Lead/Lag							Lead				Lag	
Lead-Lag Optimize?							Yes				Yes	
Vehicle Extension (s)		3.0		3.0	3.0		3.0	3.0			3.0	
Recall Mode		None		None	None		None	Min			Min	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Walk Time (s)								7.0				
Flash Dont Walk (s)								23.0				
Pedestrian Calls (#/hr)								8				
Act Effct Green (s)		6.1					26.5	31.3			29.7	
Actuated g/C Ratio		0.18					0.78	0.93			0.88	
v/c Ratio		0.00					0.02	0.16			0.15	
Control Delay		0.0					1.2	1.2			4.0	
Queue Delay		0.0					0.0	0.0			0.0	
Total Delay		0.0					1.2	1.2			4.0	
LOS		A					A	A			A	
Approach Delay								1.2			4.0	
Approach LOS								A			A	
Queue Length 50th (ft)		0					1	0			0	
Queue Length 95th (ft)		0					4	22			82	
Internal Link Dist (ft)		85			351			120			303	
Turn Bay Length (ft)												
Base Capacity (vph)		1180					911	1769			1683	
Starvation Cap Reductn		0					0	155			0	
Spillback Cap Reductn		0					0	0			0	
Storage Cap Reductn		0					0	0			0	
Reduced v/c Ratio		0.00					0.02	0.17			0.14	

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 33.8
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.16
Intersection Signal Delay: 2.4 Intersection LOS: A
Intersection Capacity Utilization 29.1% ICU Level of Service A
Analysis Period (min) 15
! Phase conflict between lane groups.

Splits and Phases: 3: Transportation Way/Cottage St & Service Rd



Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (vph)	75	60	175	165	60	300
Future Volume (vph)	75	60	175	165	60	300
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0	235		0	0	
Storage Lanes	1	1		0	0	
Taper Length (ft)	25				25	
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00
Frt		0.850	0.934			
Flt Protected	0.950					0.992
Satd. Flow (prot)	1752	1417	1740	0	0	1818
Flt Permitted	0.950					0.992
Satd. Flow (perm)	1752	1417	1740	0	0	1818
Link Speed (mph)	30		30			30
Link Distance (ft)	1123		576			417
Travel Time (s)	25.5		13.1			9.5
Peak Hour Factor	0.87	0.87	0.95	0.95	0.89	0.89
Heavy Vehicles (%)	3%	14%	1%	3%	12%	2%
Adj. Flow (vph)	86	69	184	174	67	337
Shared Lane Traffic (%)						
Lane Group Flow (vph)	86	69	358	0	0	404
Enter Blocked Intersection	No	No	No	No	No	No
Lane Alignment	Left	Right	Left	Right	Left	Left
Median Width(ft)	12		0			0
Link Offset(ft)	0		0			0
Crosswalk Width(ft)	16		16			16
Two way Left Turn Lane						
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15	9		9	15	
Sign Control	Stop		Free			Free

Intersection Summary	
Area Type: Other	
Control Type: Unsignalized	
Intersection Capacity Utilization 52.6%	ICU Level of Service A
Analysis Period (min) 15	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	335	115	0	0	310	25	140	95	55	55	0	95
Future Volume (vph)	335	115	0	0	310	25	140	95	55	55	0	95
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	125		0	0		0
Storage Lanes	1		0	0		0	1		0	1		1
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt					0.990			0.945				0.850
Flt Protected	0.950						0.950			0.950		
Satd. Flow (prot)	1770	1863	0	0	1881	0	1805	1796	0	1805	0	1599
Flt Permitted	0.235						0.950			0.651		
Satd. Flow (perm)	438	1863	0	0	1881	0	1805	1796	0	1237	0	1599
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)					5			35				103
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		419			173			305			324	
Travel Time (s)		9.5			3.9			6.9			7.4	
Peak Hour Factor	0.99	0.99	0.99	0.98	0.98	0.98	0.90	0.90	0.90	0.92	0.92	0.92
Heavy Vehicles (%)	2%	2%	2%	0%	0%	0%	0%	0%	0%	0%	0%	1%
Adj. Flow (vph)	338	116	0	0	316	26	156	106	61	60	0	103
Shared Lane Traffic (%)												
Lane Group Flow (vph)	338	116	0	0	342	0	156	167	0	60	0	103
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		12			12			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	pm+pt	NA			NA		pm+pt	NA		Perm		pt+ov
Protected Phases	7	4			8		1	6				2 7
Permitted Phases	4						6			2		
Detector Phase	7	4			8		1	6		2		2 7
Switch Phase												
Minimum Initial (s)	5.0	5.0			5.0		5.0	5.0		5.5		
Minimum Split (s)	27.0	10.0			27.0		10.0	10.0		10.0		
Total Split (s)	27.0	54.0			27.0		15.0	26.0		11.0		
Total Split (%)	33.8%	67.5%			33.8%		18.8%	32.5%		13.8%		
Maximum Green (s)	22.0	49.5			22.5		10.0	21.0		6.5		
Yellow Time (s)	3.0	3.0			3.0		3.0	3.0		3.0		
All-Red Time (s)	2.0	1.5			1.5		2.0	2.0		1.5		
Lost Time Adjust (s)	0.0	0.0			0.0		0.0	0.0		0.0		
Total Lost Time (s)	5.0	4.5			4.5		5.0	5.0		4.5		
Lead/Lag	Lead				Lag		Lead			Lag		
Lead-Lag Optimize?	Yes				Yes		Yes			Yes		
Vehicle Extension (s)	3.0	3.0			3.0		3.0	3.0		3.0		
Recall Mode	None	None			None		None	Min		Min		

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Act Effct Green (s)	34.1	32.9			16.4		17.1	17.0		6.9		29.8
Actuated g/C Ratio	0.51	0.50			0.25		0.26	0.26		0.10		0.45
v/c Ratio	0.58	0.13			0.73		0.33	0.34		0.47		0.13
Control Delay	13.4	6.9			34.5		23.9	19.7		48.0		3.8
Queue Delay	0.0	0.0			0.0		0.0	0.0		0.0		0.0
Total Delay	13.4	6.9			34.5		23.9	19.7		48.0		3.8
LOS	B	A			C		C	B		D		A
Approach Delay		11.8			34.5			21.7			20.1	
Approach LOS		B			C			C			C	
Queue Length 50th (ft)	72	21			137		52	43		26		0
Queue Length 95th (ft)	129	41			235		114	105		#85		27
Internal Link Dist (ft)		339			93			225			244	
Turn Bay Length (ft)							125					
Base Capacity (vph)	717	1397			679		497	626		128		871
Starvation Cap Reductn	0	0			0		0	0		0		0
Spillback Cap Reductn	0	0			0		0	0		0		0
Storage Cap Reductn	0	0			0		0	0		0		0
Reduced v/c Ratio	0.47	0.08			0.50		0.31	0.27		0.47		0.12

Intersection Summary

Area Type: Other
Cycle Length: 80
Actuated Cycle Length: 66.3
Natural Cycle: 75
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.73
Intersection Signal Delay: 21.4 Intersection LOS: C
Intersection Capacity Utilization 63.1% ICU Level of Service B
Analysis Period (min) 15
\# 95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1: Service Rd & Hotel Dr

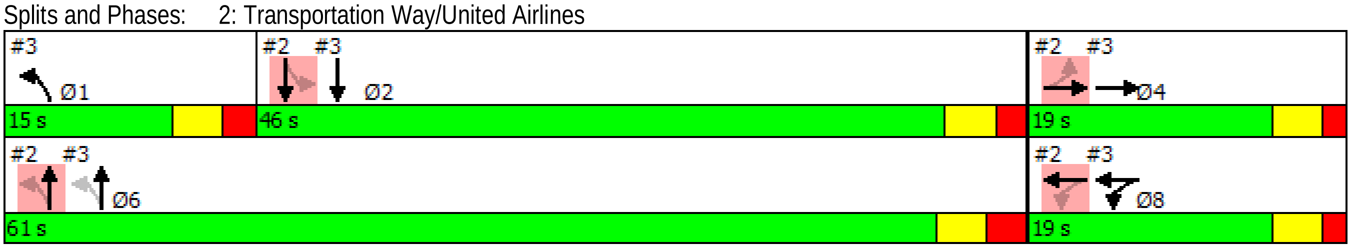
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	15	0	5	0	2	5	85	370	0	0	110	125
Future Volume (vph)	15	0	5	0	2	5	85	370	0	0	110	125
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.95	0.95	0.95	0.95	0.95
Ped Bike Factor												
Frt		0.968			0.904						0.920	
Flt Protected		0.963						0.991				
Satd. Flow (prot)	0	1736	0	0	1684	0	0	3507	0	0	3256	0
Flt Permitted								0.843				
Satd. Flow (perm)	0	1803	0	0	1684	0	0	2984	0	0	3256	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)		102			5						136	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		216			223			107			200	
Travel Time (s)		4.9			5.1			2.4			4.5	
Confl. Peds. (#/hr)				5								
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Adj. Flow (vph)	16	0	5	0	2	5	92	402	0	0	120	136
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	21	0	0	7	0	0	494	0	0	256	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			0			0	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	Perm	NA			NA		Perm	NA			NA	
Protected Phases		4			8			6			2	
Permitted Phases	4			8			6			2		
Detector Phase	4	4		8	8		6	6		2	2	
Switch Phase												
Minimum Initial (s)	5.0	5.0		5.0	5.0		9.5	9.5		10.0	10.0	
Minimum Split (s)	15.0	15.0		15.0	15.0		15.0	15.0		15.0	15.0	
Total Split (s)	19.0	19.0		19.0	19.0		61.0	61.0		46.0	46.0	
Total Split (%)	23.8%	23.8%		23.8%	23.8%		76.3%	76.3%		57.5%	57.5%	
Maximum Green (s)	14.5	14.5		14.5	14.5		55.5	55.5		41.0	41.0	
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		2.5	2.5		2.0	2.0	
Lost Time Adjust (s)		0.0			0.0			0.0			0.0	
Total Lost Time (s)		4.5			4.5			5.5			5.0	
Lead/Lag										Lag	Lag	
Lead-Lag Optimize?										Yes	Yes	
Vehicle Extension (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
Recall Mode	None	None		None	None		Min	Min		Min	Min	
Walk Time (s)							7.0	7.0				
Flash Dont Walk (s)							23.0	23.0				

Lane Group	Ø1
Lane Configurations	
Traffic Volume (vph)	
Future Volume (vph)	
Ideal Flow (vphpl)	
Lane Util. Factor	
Ped Bike Factor	
Frt	
Flt Protected	
Satd. Flow (prot)	
Flt Permitted	
Satd. Flow (perm)	
Right Turn on Red	
Satd. Flow (RTOR)	
Link Speed (mph)	
Link Distance (ft)	
Travel Time (s)	
Confl. Peds. (#/hr)	
Peak Hour Factor	
Adj. Flow (vph)	
Shared Lane Traffic (%)	
Lane Group Flow (vph)	
Enter Blocked Intersection	
Lane Alignment	
Median Width(ft)	
Link Offset(ft)	
Crosswalk Width(ft)	
Two way Left Turn Lane	
Headway Factor	
Turning Speed (mph)	
Turn Type	
Protected Phases	1
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	5.0
Minimum Split (s)	10.0
Total Split (s)	15.0
Total Split (%)	19%
Maximum Green (s)	10.0
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	Lead
Lead-Lag Optimize?	Yes
Vehicle Extension (s)	3.0
Recall Mode	None
Walk Time (s)	
Flash Dont Walk (s)	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Pedestrian Calls (#/hr)							6	6				
Act Effct Green (s)		5.8			5.8			31.1			25.9	
Actuated g/C Ratio		0.17			0.17			0.93			0.78	
v/c Ratio		0.05			0.02			0.18			0.10	
Control Delay		0.3			11.7			1.3			0.4	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		0.3			11.7			1.3			0.4	
LOS		A			B			A			A	
Approach Delay		0.3			11.7			1.3			0.4	
Approach LOS		A			B			A			A	
Queue Length 50th (ft)		0			0			0			0	
Queue Length 95th (ft)		0			9			36			0	
Internal Link Dist (ft)		136			143			27			120	
Turn Bay Length (ft)												
Base Capacity (vph)		861			754			2984			3186	
Starvation Cap Reductn		0			0			0			168	
Spillback Cap Reductn		0			0			0			0	
Storage Cap Reductn		0			0			0			0	
Reduced v/c Ratio		0.02			0.01			0.17			0.08	

Intersection Summary	
Area Type: Other	
Cycle Length: 80	
Actuated Cycle Length: 33.4	
Natural Cycle: 40	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.20	
Intersection Signal Delay: 1.1	Intersection LOS: A
Intersection Capacity Utilization 41.3%	ICU Level of Service A
Analysis Period (min) 15	

Splits and Phases: 2: Transportation Way/United Airlines



Lane Group	Ø1
Pedestrian Calls (#/hr)	
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	
Queue Length 50th (ft)	
Queue Length 95th (ft)	
Internal Link Dist (ft)	
Turn Bay Length (ft)	
Base Capacity (vph)	
Starvation Cap Reductn	
Spillback Cap Reductn	
Storage Cap Reductn	
Reduced v/c Ratio	

Intersection Summary

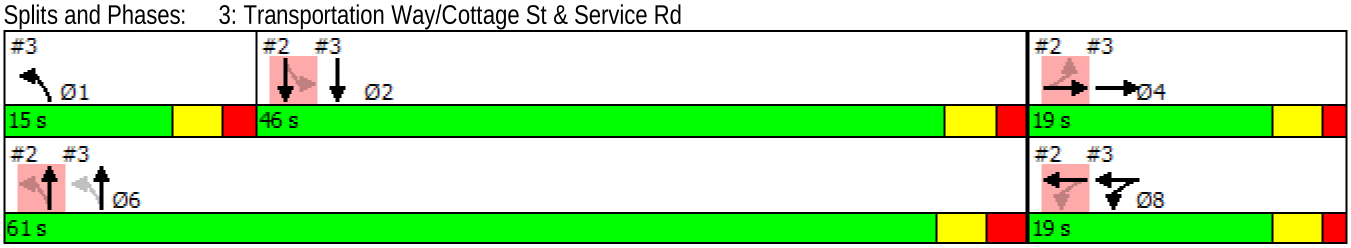
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	0	5	0	0	0	5	50	315	25	0	230	20
Future Volume (vph)	0	5	0	0	0	5	50	315	25	0	230	20
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	0		0	0		165
Storage Lanes	0		0	0		0	1		0	0		0
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt					0.865			0.989			0.989	
Flt Protected							0.950					
Satd. Flow (prot)	0	1900	0	0	1644	0	1805	1845	0	0	1862	0
Flt Permitted							0.480					
Satd. Flow (perm)	0	1900	0	0	1644	0	912	1845	0	0	1862	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)					598			12			8	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		178			431			200			383	
Travel Time (s)		4.0			9.8			4.5			8.7	
Peak Hour Factor	0.67	0.67	0.67	0.75	0.75	0.75	0.97	0.97	0.97	0.90	0.90	0.90
Heavy Vehicles (%)	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%	1%	0%
Adj. Flow (vph)	0	7	0	0	0	7	52	325	26	0	256	22
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	7	0	0	7	0	52	351	0	0	278	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type		NA			NA		pm+pt	NA			NA	
Protected Phases		4!		8!	8		1	6			2	
Permitted Phases							6					
Detector Phase		4		8	8		1	6			2	
Switch Phase												
Minimum Initial (s)		5.0		5.0	5.0		5.0	9.5			10.0	
Minimum Split (s)		15.0		15.0	15.0		10.0	15.0			15.0	
Total Split (s)		19.0		19.0	19.0		15.0	61.0			46.0	
Total Split (%)		23.8%		23.8%	23.8%		18.8%	76.3%			57.5%	
Maximum Green (s)		14.5		14.5	14.5		10.0	55.5			41.0	
Yellow Time (s)		3.0		3.0	3.0		3.0	3.0			3.0	
All-Red Time (s)		1.5		1.5	1.5		2.0	2.5			2.0	
Lost Time Adjust (s)		0.0			0.0		0.0	0.0			0.0	
Total Lost Time (s)		4.5			4.5		5.0	5.5			5.0	
Lead/Lag							Lead				Lag	
Lead-Lag Optimize?							Yes				Yes	
Vehicle Extension (s)		3.0		3.0	3.0		3.0	3.0			3.0	
Recall Mode		None		None	None		None	Min			Min	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Walk Time (s)								7.0				
Flash Dont Walk (s)								23.0				
Pedestrian Calls (#/hr)								6				
Act Effct Green (s)		5.8			5.8		26.7	31.1			25.9	
Actuated g/C Ratio		0.17			0.17		0.80	0.93			0.78	
v/c Ratio		0.02			0.01		0.06	0.20			0.19	
Control Delay		14.6			0.0		1.0	0.8			5.2	
Queue Delay		0.0			0.0		0.0	0.0			0.0	
Total Delay		14.6			0.0		1.0	0.8			5.2	
LOS		B			A		A	A			A	
Approach Delay		14.6						0.8			5.2	
Approach LOS		B						A			A	
Queue Length 50th (ft)		1			0		0	0			0	
Queue Length 95th (ft)		7			0		4	19			90	
Internal Link Dist (ft)		98			351			120			303	
Turn Bay Length (ft)												
Base Capacity (vph)		848			1065		1004	1845			1820	
Starvation Cap Reductn		0			0		0	120			0	
Spillback Cap Reductn		0			0		0	0			0	
Storage Cap Reductn		0			0		0	0			0	
Reduced v/c Ratio		0.01			0.01		0.05	0.20			0.15	

Intersection Summary

Area Type: Other
Cycle Length: 80
Actuated Cycle Length: 33.4
Natural Cycle: 40
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.20
Intersection Signal Delay: 2.7 Intersection LOS: A
Intersection Capacity Utilization 33.7% ICU Level of Service A
Analysis Period (min) 15
! Phase conflict between lane groups.

Splits and Phases: 3: Transportation Way/Cottage St & Service Rd



Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (vph)	50	45	280	40	25	200
Future Volume (vph)	50	45	280	40	25	200
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0	235		0	0	
Storage Lanes	1	1		0	0	
Taper Length (ft)	25				25	
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00
Frt		0.850	0.983			
Flt Protected	0.950					0.994
Satd. Flow (prot)	1805	1509	1831	0	0	1843
Flt Permitted	0.950					0.994
Satd. Flow (perm)	1805	1509	1831	0	0	1843
Link Speed (mph)	30		30			30
Link Distance (ft)	1123		576			417
Travel Time (s)	25.5		13.1			9.5
Peak Hour Factor	0.95	0.95	0.97	0.97	0.87	0.87
Heavy Vehicles (%)	0%	7%	2%	2%	6%	2%
Adj. Flow (vph)	53	47	289	41	29	230
Shared Lane Traffic (%)						
Lane Group Flow (vph)	53	47	330	0	0	259
Enter Blocked Intersection	No	No	No	No	No	No
Lane Alignment	Left	Right	Left	Right	Left	Left
Median Width(ft)	12		0			0
Link Offset(ft)	0		0			0
Crosswalk Width(ft)	16		16			16
Two way Left Turn Lane						
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15	9		9	15	
Sign Control	Stop		Free			Free

Intersection Summary	
Area Type: Other	
Control Type: Unsignalized	
Intersection Capacity Utilization 41.5%	ICU Level of Service A
Analysis Period (min) 15	

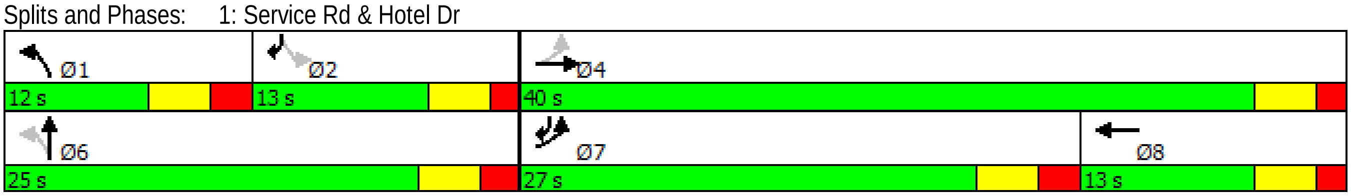
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	390	215	0	0	165	10	40	155	65	85	0	205
Future Volume (vph)	390	215	0	0	165	10	40	155	65	85	0	205
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	125		0	0		0
Storage Lanes	1		0	0		0	1		0	1		1
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt					0.992			0.956				0.850
Flt Protected	0.950						0.950			0.950		
Satd. Flow (prot)	1770	1900	0	0	1885	0	1805	1816	0	1770	0	1583
Flt Permitted	0.367						0.950			0.611		
Satd. Flow (perm)	684	1900	0	0	1885	0	1805	1816	0	1138	0	1583
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)					4			34				228
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		419			173			305			324	
Travel Time (s)		9.5			3.9			6.9			7.4	
Peak Hour Factor	0.87	0.87	0.87	0.98	0.98	0.98	0.93	0.93	0.93	0.90	0.90	0.90
Heavy Vehicles (%)	2%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	2%
Adj. Flow (vph)	448	247	0	0	168	10	43	167	70	94	0	228
Shared Lane Traffic (%)												
Lane Group Flow (vph)	448	247	0	0	178	0	43	237	0	94	0	228
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		12			12			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	pm+pt	NA			NA		pm+pt	NA		Perm		pt+ov
Protected Phases	7	4			8		1	6				2 7
Permitted Phases	4						6			2		
Detector Phase	7	4			8		1	6		2		2 7
Switch Phase												
Minimum Initial (s)	5.0	5.0			5.0		5.0	5.0		5.5		
Minimum Split (s)	27.0	10.0			10.0		10.0	10.0		10.0		
Total Split (s)	27.0	40.0			13.0		12.0	25.0		13.0		
Total Split (%)	41.5%	61.5%			20.0%		18.5%	38.5%		20.0%		
Maximum Green (s)	22.0	35.5			8.5		7.0	20.0		8.5		
Yellow Time (s)	3.0	3.0			3.0		3.0	3.0		3.0		
All-Red Time (s)	2.0	1.5			1.5		2.0	2.0		1.5		
Lost Time Adjust (s)	0.0	0.0			0.0		0.0	0.0		0.0		
Total Lost Time (s)	5.0	4.5			4.5		5.0	5.0		4.5		
Lead/Lag	Lead				Lag		Lead			Lag		
Lead-Lag Optimize?	Yes				Yes		Yes			Yes		
Vehicle Extension (s)	3.0	3.0			3.0		3.0	3.0		3.0		
Recall Mode	None	None			None		None	Min		Min		

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Act Effct Green (s)	27.6	26.9			8.4		12.6	12.6		9.1		32.1
Actuated g/C Ratio	0.51	0.50			0.16		0.23	0.23		0.17		0.60
v/c Ratio	0.63	0.26			0.60		0.10	0.53		0.49		0.22
Control Delay	12.8	7.7			35.1		17.1	20.2		36.1		1.9
Queue Delay	0.0	0.0			0.0		0.0	0.0		0.0		0.0
Total Delay	12.8	7.7			35.1		17.1	20.2		36.1		1.9
LOS	B	A			D		B	C		D		A
Approach Delay		11.0			35.1			19.8			11.9	
Approach LOS		B			D			B			B	
Queue Length 50th (ft)	61	28			53		12	60		27		0
Queue Length 95th (ft)	157	78			#154		32	118		#100		26
Internal Link Dist (ft)		339			93			225			244	
Turn Bay Length (ft)							125					
Base Capacity (vph)	855	1307			313		426	724		201		1145
Starvation Cap Reductn	0	0			0		0	0		0		0
Spillback Cap Reductn	0	0			0		0	0		0		0
Storage Cap Reductn	0	0			0		0	0		0		0
Reduced v/c Ratio	0.52	0.19			0.57		0.10	0.33		0.47		0.20

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 53.8
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.63
Intersection Signal Delay: 15.7 — Intersection LOS: B
Intersection Capacity Utilization 62.7% — ICU Level of Service B
Analysis Period (min) 15
95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1: Service Rd & Hotel Dr



Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	15	0	0	0	0	0	30	270	0	0	165	55
Future Volume (vph)	15	0	0	0	0	0	30	270	0	0	165	55
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.95	0.95	0.95	0.95	0.95
Frt											0.962	
Flt Protected		0.950						0.995				
Satd. Flow (prot)	0	1770	0	0	1863	0	0	3522	0	0	3405	0
Flt Permitted								0.915				
Satd. Flow (perm)	0	1863	0	0	1863	0	0	3238	0	0	3405	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)											60	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		216			223			107			200	
Travel Time (s)		4.9			5.1			2.4			4.5	
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Adj. Flow (vph)	16	0	0	0	0	0	33	293	0	0	179	60
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	16	0	0	0	0	0	326	0	0	239	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			0			0	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	Perm	NA					Perm	NA			NA	
Protected Phases		4			8			2			6	
Permitted Phases	4			8			2			6		
Detector Phase	4	4		8	8		2	2		6	6	
Switch Phase												
Minimum Initial (s)	5.0	5.0		5.0	5.0		10.0	10.0		10.0	10.0	
Minimum Split (s)	22.5	22.5		22.5	22.5		23.0	23.0		35.5	35.5	
Total Split (s)	23.0	23.0		23.0	23.0		30.0	30.0		42.0	42.0	
Total Split (%)	35.4%	35.4%		35.4%	35.4%		46.2%	46.2%		64.6%	64.6%	
Maximum Green (s)	18.5	18.5		18.5	18.5		25.0	25.0		36.5	36.5	
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		2.0	2.0		2.5	2.5	
Lost Time Adjust (s)		0.0			0.0			0.0			0.0	
Total Lost Time (s)		4.5			4.5			5.0			5.5	
Lead/Lag							Lag	Lag				
Lead-Lag Optimize?							Yes	Yes				
Vehicle Extension (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
Recall Mode	None	None		None	None		Min	Min		Min	Min	
Walk Time (s)										7.0	7.0	
Flash Dont Walk (s)										23.0	23.0	
Pedestrian Calls (#/hr)										8	8	
Act Effct Green (s)		6.3						28.1			33.3	

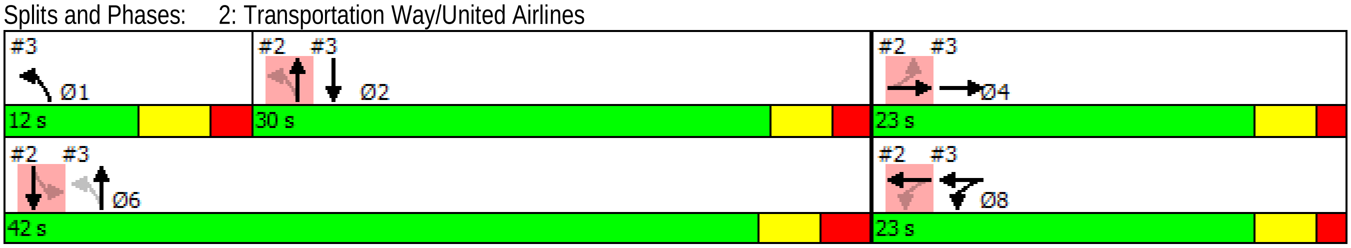
Lane Group	Ø1
Lane Configurations	
Traffic Volume (vph)	
Future Volume (vph)	
Ideal Flow (vphpl)	
Lane Util. Factor	
Frt	
Flt Protected	
Satd. Flow (prot)	
Flt Permitted	
Satd. Flow (perm)	
Right Turn on Red	
Satd. Flow (RTOR)	
Link Speed (mph)	
Link Distance (ft)	
Travel Time (s)	
Peak Hour Factor	
Adj. Flow (vph)	
Shared Lane Traffic (%)	
Lane Group Flow (vph)	
Enter Blocked Intersection	
Lane Alignment	
Median Width(ft)	
Link Offset(ft)	
Crosswalk Width(ft)	
Two way Left Turn Lane	
Headway Factor	
Turning Speed (mph)	
Turn Type	
Protected Phases	1
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	5.0
Minimum Split (s)	10.5
Total Split (s)	12.0
Total Split (%)	18%
Maximum Green (s)	6.5
Yellow Time (s)	3.5
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	Lead
Lead-Lag Optimize?	Yes
Vehicle Extension (s)	3.0
Recall Mode	None
Walk Time (s)	
Flash Dont Walk (s)	
Pedestrian Calls (#/hr)	
Act Effct Green (s)	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Actuated g/C Ratio		0.18						0.79			0.94	
v/c Ratio		0.05						0.13			0.07	
Control Delay		16.0						4.3			0.4	
Queue Delay		0.0						0.0			0.0	
Total Delay		16.0						4.3			0.4	
LOS		B						A			A	
Approach Delay		16.0						4.3			0.4	
Approach LOS		B						A			A	
Queue Length 50th (ft)		2						0			0	
Queue Length 95th (ft)		18						51			0	
Internal Link Dist (ft)		136			143			27			120	
Turn Bay Length (ft)												
Base Capacity (vph)		1014						2767			3191	
Starvation Cap Reductn		0						0			452	
Spillback Cap Reductn		0						0			0	
Storage Cap Reductn		0						0			0	
Reduced v/c Ratio		0.02						0.12			0.09	

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 35.6
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.28
Intersection Signal Delay: 3.0 Intersection LOS: A
Intersection Capacity Utilization 33.3% ICU Level of Service A
Analysis Period (min) 15

Splits and Phases: 2: Transportation Way/United Airlines



Lane Group	Ø1
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	
Queue Length 50th (ft)	
Queue Length 95th (ft)	
Internal Link Dist (ft)	
Turn Bay Length (ft)	
Base Capacity (vph)	
Starvation Cap Reductn	
Spillback Cap Reductn	
Storage Cap Reductn	
Reduced v/c Ratio	

Intersection Summary

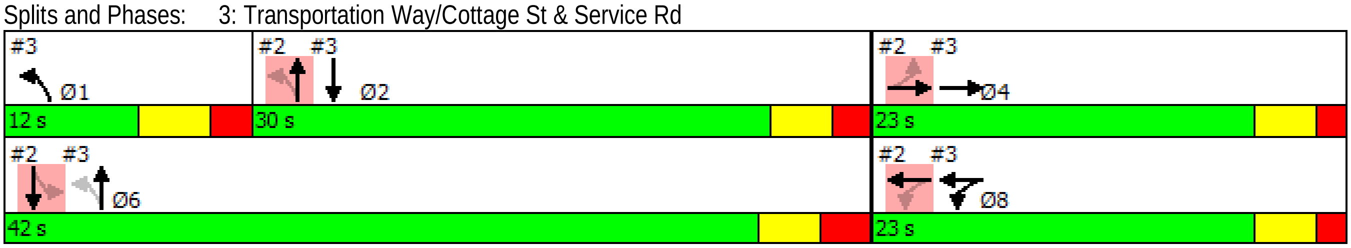
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	0	0	3	0	0	5	50	455	10	0	340	20
Future Volume (vph)	0	0	3	0	0	5	50	455	10	0	340	20
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	0		0	0		165
Storage Lanes	0		0	0		0	1		0	0		0
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt		0.865			0.865			0.997			0.992	
Flt Protected							0.950					
Satd. Flow (prot)	0	1611	0	0	1644	0	1805	1858	0	0	1850	0
Flt Permitted							0.431					
Satd. Flow (perm)	0	1611	0	0	1644	0	819	1858	0	0	1850	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)		476			358			3			5	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		165			431			200			383	
Travel Time (s)		3.8			9.8			4.5			8.7	
Peak Hour Factor	0.92	0.92	0.92	0.50	0.50	0.50	0.94	0.94	0.94	0.92	0.92	0.92
Heavy Vehicles (%)	2%	2%	2%	0%	0%	0%	0%	2%	0%	0%	2%	0%
Adj. Flow (vph)	0	0	3	0	0	10	53	484	11	0	370	22
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	3	0	0	10	0	53	495	0	0	392	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type		NA			NA		pm+pt	NA			NA	
Protected Phases		4!		8!	8		1	6			2	
Permitted Phases							6					
Detector Phase		4		8	8		1	6			2	
Switch Phase												
Minimum Initial (s)		5.0		5.0	5.0		5.0	10.0			10.0	
Minimum Split (s)		22.5		22.5	22.5		10.5	35.5			23.0	
Total Split (s)		23.0		23.0	23.0		12.0	42.0			30.0	
Total Split (%)		35.4%		35.4%	35.4%		18.5%	64.6%			46.2%	
Maximum Green (s)		18.5		18.5	18.5		6.5	36.5			25.0	
Yellow Time (s)		3.0		3.0	3.0		3.5	3.0			3.0	
All-Red Time (s)		1.5		1.5	1.5		2.0	2.5			2.0	
Lost Time Adjust (s)		0.0			0.0		0.0	0.0			0.0	
Total Lost Time (s)		4.5			4.5		5.5	5.5			5.0	
Lead/Lag							Lead				Lag	
Lead-Lag Optimize?							Yes				Yes	
Vehicle Extension (s)		3.0		3.0	3.0		3.0	3.0			3.0	
Recall Mode		None		None	None		None	Min			Min	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Walk Time (s)								7.0				
Flash Dont Walk (s)								23.0				
Pedestrian Calls (#/hr)								8				
Act Effct Green (s)		6.3			6.0		28.3	33.3			28.1	
Actuated g/C Ratio		0.18			0.17		0.79	0.94			0.79	
v/c Ratio		0.00			0.02		0.07	0.28			0.27	
Control Delay		0.0			0.0		1.4	1.5			5.4	
Queue Delay		0.0			0.0		0.0	0.0			0.0	
Total Delay		0.0			0.0		1.4	1.5			5.4	
LOS		A			A		A	A			A	
Approach Delay								1.5			5.4	
Approach LOS								A			A	
Queue Length 50th (ft)		0			0		0	1			0	
Queue Length 95th (ft)		0			0		9	55			138	
Internal Link Dist (ft)		85			351			120			303	
Turn Bay Length (ft)												
Base Capacity (vph)		1094			1058		838	1740			1581	
Starvation Cap Reductn		0			0		0	141			0	
Spillback Cap Reductn		0			0		0	0			0	
Storage Cap Reductn		0			0		0	0			0	
Reduced v/c Ratio		0.00			0.01		0.06	0.31			0.25	

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 35.6
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.28
Intersection Signal Delay: 3.1 Intersection LOS: A
Intersection Capacity Utilization 39.9% ICU Level of Service A
Analysis Period (min) 15
! Phase conflict between lane groups.

Splits and Phases: 3: Transportation Way/Cottage St & Service Rd



Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (vph)	75	45	390	70	25	285
Future Volume (vph)	75	45	390	70	25	285
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0	235		0	0	
Storage Lanes	1	1		0	0	
Taper Length (ft)	25				25	
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00
Frt		0.850	0.979			
Flt Protected	0.950					0.996
Satd. Flow (prot)	1752	1417	1836	0	0	1841
Flt Permitted	0.950					0.996
Satd. Flow (perm)	1752	1417	1836	0	0	1841
Link Speed (mph)	30		30			30
Link Distance (ft)	1123		576			417
Travel Time (s)	25.5		13.1			9.5
Peak Hour Factor	0.87	0.87	0.95	0.95	0.89	0.89
Heavy Vehicles (%)	3%	14%	1%	3%	12%	2%
Adj. Flow (vph)	86	52	411	74	28	320
Shared Lane Traffic (%)						
Lane Group Flow (vph)	86	52	485	0	0	348
Enter Blocked Intersection	No	No	No	No	No	No
Lane Alignment	Left	Right	Left	Right	Left	Left
Median Width(ft)	12		0			0
Link Offset(ft)	0		0			0
Crosswalk Width(ft)	16		16			16
Two way Left Turn Lane						
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15	9		9	15	
Sign Control	Stop		Free			Free

Intersection Summary

Area Type: Other

Control Type: Unsignalized

Intersection Capacity Utilization 46.5% ICU Level of Service A

Analysis Period (min) 15

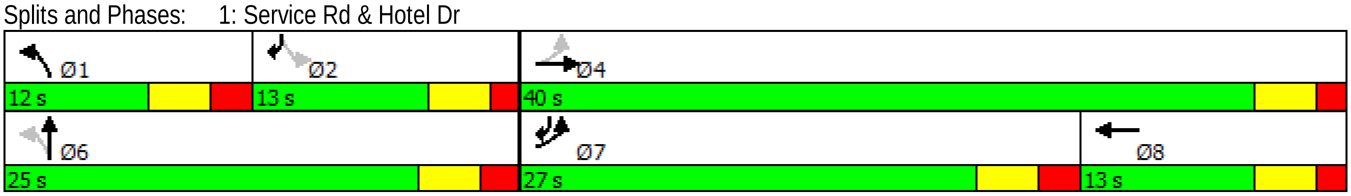
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	400	215	0	0	165	5	40	150	65	110	0	205
Future Volume (vph)	400	215	0	0	165	5	40	150	65	110	0	205
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	125		0	0		0
Storage Lanes	1		0	0		0	1		0	1		1
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt					0.996			0.955				0.850
Flt Protected	0.950						0.950			0.950		
Satd. Flow (prot)	1770	1900	0	0	1892	0	1805	1814	0	1770	0	1583
Flt Permitted	0.357						0.950			0.615		
Satd. Flow (perm)	665	1900	0	0	1892	0	1805	1814	0	1146	0	1583
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)					2			35				228
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		419			173			305			324	
Travel Time (s)		9.5			3.9			6.9			7.4	
Peak Hour Factor	0.87	0.87	0.87	0.98	0.98	0.98	0.93	0.93	0.93	0.90	0.90	0.90
Heavy Vehicles (%)	2%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	2%
Adj. Flow (vph)	460	247	0	0	168	5	43	161	70	122	0	228
Shared Lane Traffic (%)												
Lane Group Flow (vph)	460	247	0	0	173	0	43	231	0	122	0	228
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		12			12			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	pm+pt	NA			NA		pm+pt	NA		Perm		pt+ov
Protected Phases	7	4			8		1	6				2 7
Permitted Phases	4						6			2		
Detector Phase	7	4			8		1	6		2		2 7
Switch Phase												
Minimum Initial (s)	5.0	5.0			5.0		5.0	5.0		5.5		
Minimum Split (s)	27.0	10.0			10.0		10.0	10.0		10.0		
Total Split (s)	27.0	40.0			13.0		12.0	25.0		13.0		
Total Split (%)	41.5%	61.5%			20.0%		18.5%	38.5%		20.0%		
Maximum Green (s)	22.0	35.5			8.5		7.0	20.0		8.5		
Yellow Time (s)	3.0	3.0			3.0		3.0	3.0		3.0		
All-Red Time (s)	2.0	1.5			1.5		2.0	2.0		1.5		
Lost Time Adjust (s)	0.0	0.0			0.0		0.0	0.0		0.0		
Total Lost Time (s)	5.0	4.5			4.5		5.0	5.0		4.5		
Lead/Lag	Lead				Lag		Lead			Lag		
Lead-Lag Optimize?	Yes				Yes		Yes			Yes		
Vehicle Extension (s)	3.0	3.0			3.0		3.0	3.0		3.0		
Recall Mode	None	None			None		None	Min		Min		

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Act Effct Green (s)	27.9	26.6			8.7		13.0	13.0		9.7		35.3
Actuated g/C Ratio	0.54	0.51			0.17		0.25	0.25		0.19		0.68
v/c Ratio	0.61	0.25			0.55		0.10	0.48		0.57		0.20
Control Delay	11.9	7.4			33.0		17.1	19.1		40.6		1.8
Queue Delay	0.0	0.0			0.0		0.0	0.0		0.0		0.0
Total Delay	11.9	7.4			33.0		17.1	19.1		40.6		1.8
LOS	B	A			C		B	B		D		A
Approach Delay		10.3			33.0			18.8			15.3	
Approach LOS		B			C			B			B	
Queue Length 50th (ft)	63	28			53		12	58		36		0
Queue Length 95th (ft)	163	78			#150		32	114		#132		26
Internal Link Dist (ft)		339			93			225			244	
Turn Bay Length (ft)							125					
Base Capacity (vph)	924	1332			342		452	788		219		1156
Starvation Cap Reductn	0	0			0		0	0		0		0
Spillback Cap Reductn	0	0			0		0	0		0		0
Storage Cap Reductn	0	0			0		0	0		0		0
Reduced v/c Ratio	0.50	0.19			0.51		0.10	0.29		0.56		0.20

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 51.9
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.61
Intersection Signal Delay: 15.6 Intersection LOS: B
Intersection Capacity Utilization 64.1% ICU Level of Service C
Analysis Period (min) 15
95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1: Service Rd & Hotel Dr



Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	15	0	0	0	0	0	30	270	0	0	165	55
Future Volume (vph)	15	0	0	0	0	0	30	270	0	0	165	55
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.95	0.95	0.95	0.95	0.95
Frt											0.962	
Flt Protected		0.950						0.995				
Satd. Flow (prot)	0	1770	0	0	1863	0	0	3522	0	0	3405	0
Flt Permitted								0.915				
Satd. Flow (perm)	0	1863	0	0	1863	0	0	3238	0	0	3405	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)											60	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		216			223			107			200	
Travel Time (s)		4.9			5.1			2.4			4.5	
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Adj. Flow (vph)	16	0	0	0	0	0	33	293	0	0	179	60
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	16	0	0	0	0	0	326	0	0	239	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			0			0	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type	Perm	NA					Perm	NA			NA	
Protected Phases		4			8			2			6	
Permitted Phases	4			8			2			6		
Detector Phase	4	4		8	8		2	2		6	6	
Switch Phase												
Minimum Initial (s)	5.0	5.0		5.0	5.0		10.0	10.0		10.0	10.0	
Minimum Split (s)	22.5	22.5		22.5	22.5		23.0	23.0		35.5	35.5	
Total Split (s)	23.0	23.0		23.0	23.0		30.0	30.0		42.0	42.0	
Total Split (%)	35.4%	35.4%		35.4%	35.4%		46.2%	46.2%		64.6%	64.6%	
Maximum Green (s)	18.5	18.5		18.5	18.5		25.0	25.0		36.5	36.5	
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		2.0	2.0		2.5	2.5	
Lost Time Adjust (s)		0.0			0.0			0.0			0.0	
Total Lost Time (s)		4.5			4.5			5.0			5.5	
Lead/Lag							Lag	Lag				
Lead-Lag Optimize?							Yes	Yes				
Vehicle Extension (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
Recall Mode	None	None		None	None		Min	Min		Min	Min	
Walk Time (s)										7.0	7.0	
Flash Dont Walk (s)										23.0	23.0	
Pedestrian Calls (#/hr)										8	8	
Act Effct Green (s)		6.3						28.3			33.5	

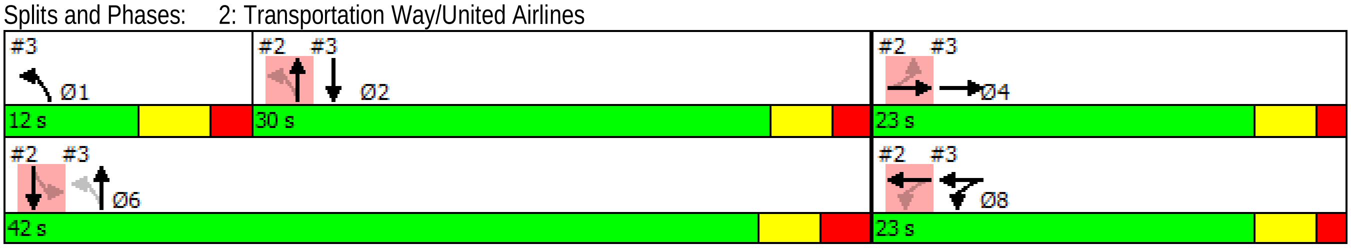
Lane Group	Ø1
Lane Configurations	
Traffic Volume (vph)	
Future Volume (vph)	
Ideal Flow (vphpl)	
Lane Util. Factor	
Frt	
Flt Protected	
Satd. Flow (prot)	
Flt Permitted	
Satd. Flow (perm)	
Right Turn on Red	
Satd. Flow (RTOR)	
Link Speed (mph)	
Link Distance (ft)	
Travel Time (s)	
Peak Hour Factor	
Adj. Flow (vph)	
Shared Lane Traffic (%)	
Lane Group Flow (vph)	
Enter Blocked Intersection	
Lane Alignment	
Median Width(ft)	
Link Offset(ft)	
Crosswalk Width(ft)	
Two way Left Turn Lane	
Headway Factor	
Turning Speed (mph)	
Turn Type	
Protected Phases	1
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	5.0
Minimum Split (s)	10.5
Total Split (s)	12.0
Total Split (%)	18%
Maximum Green (s)	6.5
Yellow Time (s)	3.5
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	Lead
Lead-Lag Optimize?	Yes
Vehicle Extension (s)	3.0
Recall Mode	None
Walk Time (s)	
Flash Dont Walk (s)	
Pedestrian Calls (#/hr)	
Act Effct Green (s)	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Actuated g/C Ratio		0.18						0.79			0.94	
v/c Ratio		0.05						0.13			0.07	
Control Delay		16.1						4.3			0.4	
Queue Delay		0.0						0.0			0.0	
Total Delay		16.1						4.3			0.4	
LOS		B						A			A	
Approach Delay		16.1						4.3			0.4	
Approach LOS		B						A			A	
Queue Length 50th (ft)		2						0			0	
Queue Length 95th (ft)		18						51			0	
Internal Link Dist (ft)		136			143			27			120	
Turn Bay Length (ft)												
Base Capacity (vph)		1010						2760			3189	
Starvation Cap Reductn		0						0			454	
Spillback Cap Reductn		0						0			0	
Storage Cap Reductn		0						0			0	
Reduced v/c Ratio		0.02						0.12			0.09	

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 35.8
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.30
Intersection Signal Delay: 3.0 Intersection LOS: A
Intersection Capacity Utilization 33.3% ICU Level of Service A
Analysis Period (min) 15

Splits and Phases: 2: Transportation Way/United Airlines



Lane Group	Ø1
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	
Queue Length 50th (ft)	
Queue Length 95th (ft)	
Internal Link Dist (ft)	
Turn Bay Length (ft)	
Base Capacity (vph)	
Starvation Cap Reductn	
Spillback Cap Reductn	
Storage Cap Reductn	
Reduced v/c Ratio	

Intersection Summary

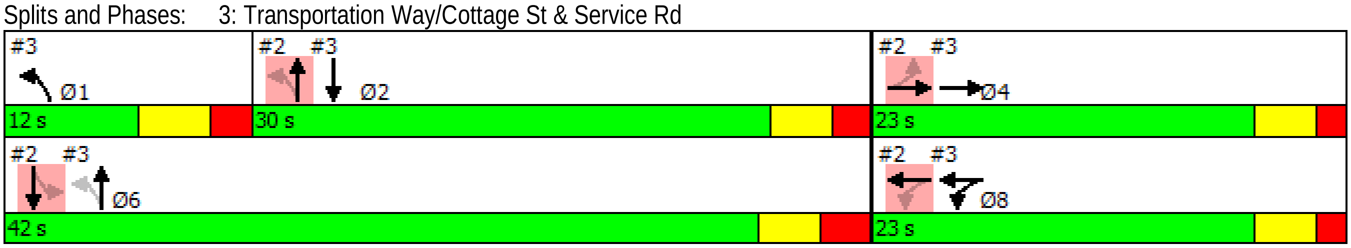
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	0	0	3	0	0	5	50	475	10	0	355	20
Future Volume (vph)	0	0	3	0	0	5	50	475	10	0	355	20
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0		0	0		0	0		0	0		165
Storage Lanes	0		0	0		0	1		0	0		0
Taper Length (ft)	25			25			25			25		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frt		0.865			0.865			0.997			0.993	
Flt Protected							0.950					
Satd. Flow (prot)	0	1611	0	0	1644	0	1805	1858	0	0	1852	0
Flt Permitted							0.421					
Satd. Flow (perm)	0	1611	0	0	1644	0	800	1858	0	0	1852	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)		463			340			3			5	
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		165			431			200			383	
Travel Time (s)		3.8			9.8			4.5			8.7	
Peak Hour Factor	0.92	0.92	0.92	0.50	0.50	0.50	0.94	0.94	0.94	0.92	0.92	0.92
Heavy Vehicles (%)	2%	2%	2%	0%	0%	0%	0%	2%	0%	0%	2%	0%
Adj. Flow (vph)	0	0	3	0	0	10	53	505	11	0	386	22
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	3	0	0	10	0	53	516	0	0	408	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			0			12			12	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type		NA			NA		pm+pt	NA			NA	
Protected Phases		4!		8!	8		1	6			2	
Permitted Phases							6					
Detector Phase		4		8	8		1	6			2	
Switch Phase												
Minimum Initial (s)		5.0		5.0	5.0		5.0	10.0			10.0	
Minimum Split (s)		22.5		22.5	22.5		10.5	35.5			23.0	
Total Split (s)		23.0		23.0	23.0		12.0	42.0			30.0	
Total Split (%)		35.4%		35.4%	35.4%		18.5%	64.6%			46.2%	
Maximum Green (s)		18.5		18.5	18.5		6.5	36.5			25.0	
Yellow Time (s)		3.0		3.0	3.0		3.5	3.0			3.0	
All-Red Time (s)		1.5		1.5	1.5		2.0	2.5			2.0	
Lost Time Adjust (s)		0.0			0.0		0.0	0.0			0.0	
Total Lost Time (s)		4.5			4.5		5.5	5.5			5.0	
Lead/Lag							Lead				Lag	
Lead-Lag Optimize?							Yes				Yes	
Vehicle Extension (s)		3.0		3.0	3.0		3.0	3.0			3.0	
Recall Mode		None		None	None		None	Min			Min	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Walk Time (s)								7.0				
Flash Dont Walk (s)								23.0				
Pedestrian Calls (#/hr)								8				
Act Effct Green (s)		6.3			6.0		28.4	33.5			28.3	
Actuated g/C Ratio		0.18			0.17		0.79	0.94			0.79	
v/c Ratio		0.00			0.02		0.07	0.30			0.28	
Control Delay		0.0			0.0		1.4	1.5			5.4	
Queue Delay		0.0			0.0		0.0	0.0			0.0	
Total Delay		0.0			0.0		1.4	1.5			5.4	
LOS		A			A		A	A			A	
Approach Delay								1.5			5.4	
Approach LOS								A			A	
Queue Length 50th (ft)		0			0		0	1			0	
Queue Length 95th (ft)		0			0		9	58			144	
Internal Link Dist (ft)		85			351			120			303	
Turn Bay Length (ft)												
Base Capacity (vph)		1085			1046		827	1738			1579	
Starvation Cap Reductn		0			0		0	137			0	
Spillback Cap Reductn		0			0		0	0			0	
Storage Cap Reductn		0			0		0	0			0	
Reduced v/c Ratio		0.00			0.01		0.06	0.32			0.26	

Intersection Summary

Area Type: Other
Cycle Length: 65
Actuated Cycle Length: 35.8
Natural Cycle: 60
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.30
Intersection Signal Delay: 3.1 Intersection LOS: A
Intersection Capacity Utilization 40.7% ICU Level of Service A
Analysis Period (min) 15
! Phase conflict between lane groups.

Splits and Phases: 3: Transportation Way/Cottage St & Service Rd



Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (vph)	90	55	390	90	35	285
Future Volume (vph)	90	55	390	90	35	285
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Storage Length (ft)	0	235		0	0	
Storage Lanes	1	1		0	0	
Taper Length (ft)	25				25	
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00
Frt		0.850	0.975			
Flt Protected	0.950					0.995
Satd. Flow (prot)	1752	1417	1827	0	0	1834
Flt Permitted	0.950					0.995
Satd. Flow (perm)	1752	1417	1827	0	0	1834
Link Speed (mph)	30		30			30
Link Distance (ft)	1123		576			417
Travel Time (s)	25.5		13.1			9.5
Peak Hour Factor	0.87	0.87	0.95	0.95	0.89	0.89
Heavy Vehicles (%)	3%	14%	1%	3%	12%	2%
Adj. Flow (vph)	103	63	411	95	39	320
Shared Lane Traffic (%)						
Lane Group Flow (vph)	103	63	506	0	0	359
Enter Blocked Intersection	No	No	No	No	No	No
Lane Alignment	Left	Right	Left	Right	Left	Left
Median Width(ft)	12		0			0
Link Offset(ft)	0		0			0
Crosswalk Width(ft)	16		16			16
Two way Left Turn Lane						
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (mph)	15	9		9	15	
Sign Control	Stop		Free			Free

Intersection Summary	
Area Type: Other	
Control Type: Unsignalized	
Intersection Capacity Utilization 56.0%	ICU Level of Service B
Analysis Period (min) 15	

QATAR Analysis

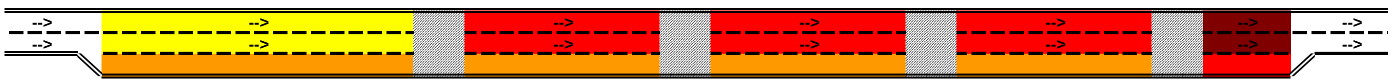
Quick Analysis Tool for Airport Roadways

QATAR v0.6 developed by LeighFisher in association with Dowling Associates, Inc.

Results: Level-of-Service by Zone

Model run by: Laura Castelli on 3/8/2019

Airport	BOS
Roadway location	Terminal E - Curb 2
Scenario	2018 Existing
Level / type of roadway	Arrivals
Total lanes / approach lanes	3 / 2
Number of curbside zones	9



Zone ID	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Name/description	pax	cw	pax	cw	pax	cw	pax	cw	cb
Curb length (feet)	190	20	115	20	115	20	115	20	50
Zone type	active	xwalk	active	xwalk	active	xwalk	active	xwalk	active
Roadway volume (vph)	780	780	780	780	780	780	780	780	780
Roadway capacity (vph)	1,373	2,657	974	2,657	974	2,657	974	2,657	722
Roadway V/C ratio	0.568	0.294	0.801	0.294	0.801	0.294	0.801	0.294	1.081
Roadway LOS	C	B	E	B	E	B	E	B	F
Curb demand (# in sys 95% of time)	11.0	N/A	8.0	N/A	8.0	N/A	8.0	N/A	2.0
Curb capacity per lane (vehicles)	8.0	N/A	5.0	N/A	5.0	N/A	5.0	N/A	1.0
Curb utilization ratio	1.375	N/A	1.600	N/A	1.600	N/A	1.600	N/A	2.000
Curb LOS	D	N/A	D	N/A	D	N/A	D	N/A	E

Level-of-service (LOS) key:

A
B
C
D
E
F

Quick Analysis Tool for Airport Roadways

QATAR v0.6 developed by LeighFisher in association with Dowling Associates, Inc.

Results: Detailed Report By Zone

Model run by: Laura Castelli on 3/8/2019

ID	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Name	pax	cw	pax	cw	pax	cw	pax	cw	cb
Type of zone	active	xwalk	active	xwalk	active	xwalk	active	xwalk	active
Curbside length (feet)	190	20	115	20	115	20	115	20	50
Number of lanes	3	3	3	3	3	3	3	3	3
Number of approach lanes	2	2	2	2	2	2	2	2	2
Roadway volume (vph)	780	780	780	780	780	780	780	780	780
Curbside demand (vph)	100	-	62	-	62	-	61	-	20
Average dwell time (minutes)	4.00	-	4.00	-	4.00	-	4.00	-	1.30
Average vehicle length (feet)	25.00	-	25.00	-	25.00	-	25.00	-	40.00
Average vehicle arrival rate (vph)	100.00	-	62.00	-	62.00	-	61.00	-	20.00
Crosswalk adjustment factor	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Regional adjustment factor	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Through lane roadway capacity	1,446	2,797	1,026	2,797	1,026	2,797	1,026	2,797	760
Adjusted through lane roadway capacity	1,373	2,657	974	2,657	974	2,657	974	2,657	722
Estimated roadway V/C ratio	0.568	0.294	0.801	0.294	0.801	0.294	0.801	0.294	1.081
Curb capacity per lane (vehicles)	8.00	-	5.00	-	5.00	-	5.00	-	1.00
Curb utilization ratio	1.375	-	1.600	-	1.600	-	1.600	-	2.000
% occupancy in lane 1	1.000	-	1.000	-	1.000	-	1.000	-	1.000
% occupancy in lane 2	0.370	-	0.545	-	0.545	-	0.545	-	0.745
% occupancy in lane 3	-	-	0.05	-	0.05	-	0.05	-	0.25
# of cars in curbside lane	8.00	-	5.00	-	5.00	-	5.00	-	1.00
# of double-parked cars	2.96	-	2.73	-	2.73	-	2.73	-	0.75
# of triple-parked cars	-	-	0.225	-	0.225	-	0.225	-	0.245
Curbside LOS	D		D		D		D		E
Roadway LOS	C	B	E	B	E	B	E	B	F

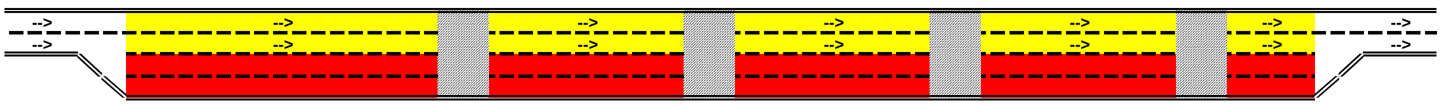
Quick Analysis Tool for Airport Roadways

QATAR v0.6 developed by LeighFisher in association with Dowling Associates, Inc.

Results: Level-of-Service by Zone

Model run by: Laura Castelli on 3/8/2019

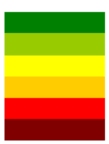
Airport	BOS
Roadway location	Terminal E - Curb 2
Scenario	50 MAP NB
Level / type of roadway	Arrivals
Total lanes / approach lanes	4 / 2
Number of curbside zones	9



Zone ID	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Name/description	pax	cw	pax	cw	pax	cw	pax	cw	cb
Curb length (feet)	190	20	115	20	115	20	115	20	50
Zone type	active	xwalk	active	xwalk	active	xwalk	active	xwalk	active
Roadway volume (vph)	1,015	1,015	1,015	1,015	1,015	1,015	1,015	1,015	1,015
Roadway capacity (vph)	1,899	2,708	1,696	2,708	1,696	2,708	1,696	2,708	1,696
Roadway V/C ratio	0.534	0.375	0.598	0.375	0.598	0.375	0.598	0.375	0.598
Roadway LOS	C	B	C	B	C	B	C	B	C
Curb demand (# in sys 95% of time)	15.0	N/A	10.0	N/A	10.0	N/A	10.0	N/A	2.0
Curb capacity per lane (vehicles)	8.0	N/A	5.0	N/A	5.0	N/A	5.0	N/A	1.0
Curb utilization ratio	1.875	N/A	2.000	N/A	2.000	N/A	2.000	N/A	2.000
Curb LOS	E	N/A	E	N/A	E	N/A	E	N/A	E

Level-of-service (LOS) key:

A
B
C
D
E
F



Quick Analysis Tool for Airport Roadways

QATAR v0.6 developed by LeighFisher in association with Dowling Associates, Inc.

Summary of Inputs and Assumptions

Model run by: Laura Castelli on 3/8/2019

Airport	BOS
Roadway location	Terminal E - Curb 2
Scenario	50 MAP NB
Level / type of roadway	Arrivals
Total lanes / approach lanes	4 / 2
Number of curbside zones	9
% of 1st lane full when next vehicle double parks	80%
% of 2nd lane full when next vehicle triple parks	50%
Crosswalk adjustment factor	100%
Regional adjustment factor	95%

Frontage and dwell time per curbside operation

Vehicle class	Vehicle parking length (feet)	Average dwell time (minutes)
Private Vehicle Pick-Up	25.0	4.0
Taxicabs	25.0	3.9
Economy Parking	40.0	1.2
MPA Employee	40.0	1.2
Water Taxi & Water Ferry	40.0	1.2
Interterminal	40.0	1.2
Rental Car and MBTA BL	70.0	1.3
Car Service	30.0	5.0
Other Shared Ride or Limo	30.0	5.0
Free Hotel or Other CS	40.0	1.3
MBTA Silver Line	70.0	0.8
Logan Express	50	2
Scheduled Bus Service	50	3
Charter Bus	50	7

Assumptions by zone

Zone ID	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Name	pax	cw	pax	cw	pax	cw	pax	cw	cb
Type	active	xwalk	active	xwalk	active	xwalk	active	xwalk	active
Curbside frontage (feet)	190	20	115	20	115	20	115	20	50
Number of lanes	4	4	4	4	4	4	4	4	4
Number of approach lanes	2	2	2	2	2	2	2	2	2

Volume of vehicles using roadway (vph)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Private Vehicle Pick-Up	995	995	995	995	995	995	995	995	995
Taxicabs	-	-	-	-	-	-	-	-	-
Economy Parking	-	-	-	-	-	-	-	-	-
MPA Employee	-	-	-	-	-	-	-	-	-
Water Taxi & Water Ferry	-	-	-	-	-	-	-	-	-
Interterminal	-	-	-	-	-	-	-	-	-
Rental Car and MBTA BL	-	-	-	-	-	-	-	-	-
Car Service	-	-	-	-	-	-	-	-	-
Other Shared Ride or Limo	-	-	-	-	-	-	-	-	-
Free Hotel or Other CS	20	20	20	20	20	20	20	20	20
MBTA Silver Line	-	-	-	-	-	-	-	-	-
Logan Express	-	-	-	-	-	-	-	-	-
Scheduled Bus Service	-	-	-	-	-	-	-	-	-
Charter Bus	-	-	-	-	-	-	-	-	-

Volume of vehicles using curbside (vph)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Private Vehicle Pick-Up	140	-	87	-	87	-	86	-	-
Taxicabs	-	-	-	-	-	-	-	-	-
Economy Parking	-	-	-	-	-	-	-	-	-
MPA Employee	-	-	-	-	-	-	-	-	-
Water Taxi & Water Ferry	-	-	-	-	-	-	-	-	-
Interterminal	-	-	-	-	-	-	-	-	-
Rental Car and MBTA BL	-	-	-	-	-	-	-	-	-
Car Service	-	-	-	-	-	-	-	-	-
Other Shared Ride or Limo	-	-	-	-	-	-	-	-	-
Free Hotel or Other CS	-	-	-	-	-	-	-	-	20
MBTA Silver Line	-	-	-	-	-	-	-	-	-
Logan Express	-	-	-	-	-	-	-	-	-
Scheduled Bus Service	-	-	-	-	-	-	-	-	-
Charter Bus	-	-	-	-	-	-	-	-	-

Quick Analysis Tool for Airport Roadways

QATAR v0.6 developed by LeighFisher in association with Dowling Associates, Inc.

Results: Detailed Report By Zone

Model run by: Laura Castelli on 3/8/2019

ID	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Name	pax	cw	pax	cw	pax	cw	pax	cw	cb
Type of zone	active	xwalk	active	xwalk	active	xwalk	active	xwalk	active
Curbside length (feet)	190	20	115	20	115	20	115	20	50
Number of lanes	4	4	4	4	4	4	4	4	4
Number of approach lanes	2	2	2	2	2	2	2	2	2
Roadway volume (vph)	1,015	1,015	1,015	1,015	1,015	1,015	1,015	1,015	1,015
Curbside demand (vph)	140	-	87	-	87	-	86	-	20
Average dwell time (minutes)	4.00	-	4.00	-	4.00	-	4.00	-	1.30
Average vehicle length (feet)	25.00	-	25.00	-	25.00	-	25.00	-	40.00
Average vehicle arrival rate (vph)	140.00	-	87.00	-	87.00	-	86.00	-	20.00
Crosswalk adjustment factor	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Regional adjustment factor	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Through lane roadway capacity	2,000	2,850	1,786	2,850	1,786	2,850	1,786	2,850	1,786
Adjusted through lane roadway capacity	1,899	2,708	1,696	2,708	1,696	2,708	1,696	2,708	1,696
Estimated roadway V/C ratio	0.534	0.375	0.598	0.375	0.598	0.375	0.598	0.375	0.598
Curb capacity per lane (vehicles)	8.00	-	5.00	-	5.00	-	5.00	-	1.00
Curb utilization ratio	1.875	-	2.000	-	2.000	-	2.000	-	2.000
% occupancy in lane 1	1.000	-	1.000	-	1.000	-	1.000	-	1.000
% occupancy in lane 2	0.685	-	0.745	-	0.745	-	0.745	-	0.745
% occupancy in lane 3	0.19	-	0.25	-	0.25	-	0.25	-	0.25
# of cars in curbside lane	8.00	-	5.00	-	5.00	-	5.00	-	1.00
# of double-parked cars	5.48	-	3.73	-	3.73	-	3.73	-	0.75
# of triple-parked cars	1.480	-	1.225	-	1.225	-	1.225	-	0.245
Curbside LOS	E		E		E		E		E
Roadway LOS	C	B	C	B	C	B	C	B	C

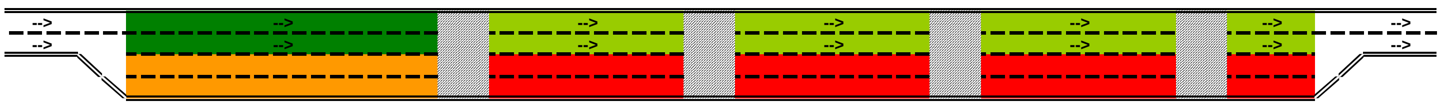
Quick Analysis Tool for Airport Roadways

QATAR v0.6 developed by LeighFisher in association with Dowling Associates, Inc.

Results: Level-of-Service by Zone

Model run by: Laura Castelli on 3/8/2019

Airport	BOS
Roadway location	Terminal E - Curb 2
Scenario	50 MAP Build
Level / type of roadway	Arrivals
Total lanes / approach lanes	4 / 2
Number of curbside zones	9



Zone ID	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Name/description	pax	cw	pax	cw	pax	cw	pax	cw	cb
Curb length (feet)	190	20	115	20	115	20	115	20	50
Zone type	active	xwalk	active	xwalk	active	xwalk	active	xwalk	active
Roadway volume (vph)	500	500	500	500	500	500	500	500	500
Roadway capacity (vph)	2,483	2,708	1,696	2,708	1,696	2,708	1,696	2,708	1,696
Roadway V/C ratio	0.201	0.185	0.295	0.185	0.295	0.185	0.295	0.185	0.295
Roadway LOS	A	A	B	A	B	A	B	A	B
Curb demand (# in sys 95% of time)	11.0	N/A	10.0	N/A	10.0	N/A	10.0	N/A	2.0
Curb capacity per lane (vehicles)	8.0	N/A	5.0	N/A	5.0	N/A	5.0	N/A	1.0
Curb utilization ratio	1.375	N/A	2.000	N/A	2.000	N/A	2.000	N/A	2.000
Curb LOS	D	N/A	E	N/A	E	N/A	E	N/A	E

Level-of-service (LOS) key:

A
B
C
D
E
F

Quick Analysis Tool for Airport Roadways

QATAR v0.6 developed by LeighFisher in association with Dowling Associates, Inc.

Summary of Inputs and Assumptions

Model run by: Laura Castelli on 3/8/2019

Airport	BOS
Roadway location	Terminal E - Curb 2
Scenario	50 MAP Build
Level / type of roadway	Arrivals
Total lanes / approach lanes	4 / 2
Number of curbside zones	9
% of 1st lane full when next vehicle double parks	80%
% of 2nd lane full when next vehicle triple parks	50%
Crosswalk adjustment factor	100%
Regional adjustment factor	95%

Frontage and dwell time per curbside operation

Vehicle class	Vehicle parking length (feet)	Average dwell time (minutes)
Private Vehicle Pick-Up	25.0	4.0
Taxicabs	25.0	3.9
Economy Parking	40.0	1.2
MPA Employee	40.0	1.2
Water Taxi & Water Ferry	40.0	1.2
Interterminal	40.0	1.2
Rental Car and MBTA BL	70.0	1.3
Car Service	30.0	5.0
Other Shared Ride or Limo	30.0	5.0
Free Hotel or Other CS	40.0	1.3
MBTA Silver Line	70.0	0.8
Logan Express	50	2
Scheduled Bus Service	50	3
Charter Bus	50	7

Assumptions by zone

Zone ID	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Name	pax	cw	pax	cw	pax	cw	pax	cw	cb
Type	active	xwalk	active	xwalk	active	xwalk	active	xwalk	active
Curbside frontage (feet)	190	20	115	20	115	20	115	20	50
Number of lanes	4	4	4	4	4	4	4	4	4
Number of approach lanes	2	2	2	2	2	2	2	2	2

Volume of vehicles using roadway (vph)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Private Vehicle Pick-Up	480	480	480	480	480	480	480	480	480
Taxicabs	-	-	-	-	-	-	-	-	-
Economy Parking	-	-	-	-	-	-	-	-	-
MPA Employee	-	-	-	-	-	-	-	-	-
Water Taxi & Water Ferry	-	-	-	-	-	-	-	-	-
Interterminal	-	-	-	-	-	-	-	-	-
Rental Car and MBTA BL	-	-	-	-	-	-	-	-	-
Car Service	-	-	-	-	-	-	-	-	-
Other Shared Ride or Limo	-	-	-	-	-	-	-	-	-
Free Hotel or Other CS	20	20	20	20	20	20	20	20	20
MBTA Silver Line	-	-	-	-	-	-	-	-	-
Logan Express	-	-	-	-	-	-	-	-	-
Scheduled Bus Service	-	-	-	-	-	-	-	-	-
Charter Bus	-	-	-	-	-	-	-	-	-

Volume of vehicles using curbside (vph)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Private Vehicle Pick-Up	100	-	87	-	87	-	86	-	-
Taxicabs	-	-	-	-	-	-	-	-	-
Economy Parking	-	-	-	-	-	-	-	-	-
MPA Employee	-	-	-	-	-	-	-	-	-
Water Taxi & Water Ferry	-	-	-	-	-	-	-	-	-
Interterminal	-	-	-	-	-	-	-	-	-
Rental Car and MBTA BL	-	-	-	-	-	-	-	-	-
Car Service	-	-	-	-	-	-	-	-	-
Other Shared Ride or Limo	-	-	-	-	-	-	-	-	-
Free Hotel or Other CS	-	-	-	-	-	-	-	-	20
MBTA Silver Line	-	-	-	-	-	-	-	-	-
Logan Express	-	-	-	-	-	-	-	-	-
Scheduled Bus Service	-	-	-	-	-	-	-	-	-
Charter Bus	-	-	-	-	-	-	-	-	-

Quick Analysis Tool for Airport Roadways

QATAR v0.6 developed by LeighFisher in association with Dowling Associates, Inc.

Results: Detailed Report By Zone

Model run by: Laura Castelli on 3/8/2019

ID	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Name	pax	cw	pax	cw	pax	cw	pax	cw	cb
Type of zone	active	xwalk	active	xwalk	active	xwalk	active	xwalk	active
Curbside length (feet)	190	20	115	20	115	20	115	20	50
Number of lanes	4	4	4	4	4	4	4	4	4
Number of approach lanes	2	2	2	2	2	2	2	2	2
Roadway volume (vph)	500	500	500	500	500	500	500	500	500
Curbside demand (vph)	100	-	87	-	87	-	86	-	20
Average dwell time (minutes)	4.00	-	4.00	-	4.00	-	4.00	-	1.30
Average vehicle length (feet)	25.00	-	25.00	-	25.00	-	25.00	-	40.00
Average vehicle arrival rate (vph)	100.00	-	87.00	-	87.00	-	86.00	-	20.00
Crosswalk adjustment factor	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Regional adjustment factor	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Through lane roadway capacity	2,615	2,850	1,786	2,850	1,786	2,850	1,786	2,850	1,786
Adjusted through lane roadway capacity	2,483	2,708	1,696	2,708	1,696	2,708	1,696	2,708	1,696
Estimated roadway V/C ratio	0.201	0.185	0.295	0.185	0.295	0.185	0.295	0.185	0.295
Curb capacity per lane (vehicles)	8.00	-	5.00	-	5.00	-	5.00	-	1.00
Curb utilization ratio	1.375	-	2.000	-	2.000	-	2.000	-	2.000
% occupancy in lane 1	1.000	-	1.000	-	1.000	-	1.000	-	1.000
% occupancy in lane 2	0.370	-	0.745	-	0.745	-	0.745	-	0.745
% occupancy in lane 3	-	-	0.25	-	0.25	-	0.25	-	0.25
# of cars in curbside lane	8.00	-	5.00	-	5.00	-	5.00	-	1.00
# of double-parked cars	2.96	-	3.73	-	3.73	-	3.73	-	0.75
# of triple-parked cars	-	-	1.225	-	1.225	-	1.225	-	0.245
Curbside LOS	D		E		E		E		E
Roadway LOS	A	A	B	A	B	A	B	A	B

Appendix F

- Air Quality/Emissions Reduction Technical Appendix
  - Example MOVES Input File and Output Files - *prepared by VHB*
  - Example CAL3QHC Input and Output Files - *prepared by VHB*
  - Energy Assessment - *prepared by WSP*

This Page Intentionally Left Blank.

```
<runspec version="MOVES2014b-20180726">
    <description><![CDATA[2030 LAPP Micro EF]]></description>
    <models>
        <model value="ONROAD"/>
    </models>
    <modelscale value="Inv"/>
    <modeldomain value="PROJECT"/>
    <geographicselections>
        <geographicselection type="COUNTY" key="25025" description="MASSACHUSETTS - Suffolk
        County"/>
    </geographicselections>
    <timespan>
        <year key="2030"/>
        <month id="1"/>
        <day id="5"/>
        <beginhour id="9"/>
        <endhour id="9"/>
        <aggregateBy key="Hour"/>
    </timespan>
    <onroadvehicleselections>
        <onroadvehicleselection fueltypeid="3" fueltypedesc="Compressed Natural Gas (CNG)"
        sourcetypeid="42" sourcetypename="Transit Bus"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="62"
        sourcetypename="Combination Long-haul Truck"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="61"
        sourcetypename="Combination Short-haul Truck"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="41"
        sourcetypename="Intercity Bus"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="32"
        sourcetypename="Light Commercial Truck"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="54"
        sourcetypename="Motor Home"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="21"
        sourcetypename="Passenger Car"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="31"
        sourcetypename="Passenger Truck"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="51"
        sourcetypename="Refuse Truck"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="43"
        sourcetypename="School Bus"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="53"
        sourcetypename="Single Unit Long-haul Truck"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="52"
        sourcetypename="Single Unit Short-haul Truck"/>
        <onroadvehicleselection fueltypeid="2" fueltypedesc="Diesel Fuel" sourcetypeid="42"
        sourcetypename="Transit Bus"/>
        <onroadvehicleselection fueltypeid="9" fueltypedesc="Electricity" sourcetypeid="32"
        sourcetypename="Light Commercial Truck"/>
        <onroadvehicleselection fueltypeid="9" fueltypedesc="Electricity" sourcetypeid="21"
        sourcetypename="Passenger Car"/>
        <onroadvehicleselection fueltypeid="9" fueltypedesc="Electricity" sourcetypeid="31"
        sourcetypename="Passenger Truck"/>
        <onroadvehicleselection fueltypeid="5" fueltypedesc="Ethanol (E-85)" sourcetypeid="32"
        sourcetypename="Light Commercial Truck"/>
        <onroadvehicleselection fueltypeid="5" fueltypedesc="Ethanol (E-85)" sourcetypeid="21"
        sourcetypename="Passenger Car"/>
        <onroadvehicleselection fueltypeid="5" fueltypedesc="Ethanol (E-85)" sourcetypeid="31"
        sourcetypename="Passenger Truck"/>
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="61"
        sourcetypename="Combination Short-haul Truck"/>
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="32"
        sourcetypename="Light Commercial Truck"/>
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="54"
        sourcetypename="Motor Home"/>
```

```
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="11"
        sourcetypename="Motorcycle"/>
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="21"
        sourcetypename="Passenger Car"/>
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="31"
        sourcetypename="Passenger Truck"/>
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="51"
        sourcetypename="Refuse Truck"/>
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="43"
        sourcetypename="School Bus"/>
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="53"
        sourcetypename="Single Unit Long-haul Truck"/>
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="52"
        sourcetypename="Single Unit Short-haul Truck"/>
        <onroadvehicleselection fueltypeid="1" fueltypedesc="Gasoline" sourcetypeid="42"
        sourcetypename="Transit Bus"/>
    </onroadvehicleselections>
    <offroadvehicleselections>
    </offroadvehicleselections>
    <offroadvehiclesccs>
    </offroadvehiclesccs>
    <roadtypes separateramps="false">
        <roadtype roadtypeid="1" roadtypename="Off-Network" modelCombination="M1"/>
        <roadtype roadtypeid="2" roadtypename="Rural Restricted Access" modelCombination="M1"/>
        <roadtype roadtypeid="3" roadtypename="Rural Unrestricted Access" modelCombination="M1"/>
        <roadtype roadtypeid="4" roadtypename="Urban Restricted Access" modelCombination="M1"/>
        <roadtype roadtypeid="5" roadtypename="Urban Unrestricted Access" modelCombination="M1"/>
    </roadtypes>
    <pollutantprocessassociations>
        <pollutantprocessassociation pollutantkey="2" pollutantname="Carbon Monoxide (CO)"
        processkey="1" processname="Running Exhaust"/>
        <pollutantprocessassociation pollutantkey="2" pollutantname="Carbon Monoxide (CO)"
        processkey="15" processname="Crankcase Running Exhaust"/>
    </pollutantprocessassociations>
    <databaseselections>
        <databaseselection servername="" databasename="2030_SuffolkLEVs" description=""/>
    </databaseselections>
    <internalcontrolstrategies>
<internalcontrolstrategy
classname="gov.epa.otaq.moves.master.implementation.ghg.internalcontrolstrategies.rateofprogress.
RateOfProgressStrategy"><![CDATA[
useParameters   No

]]></internalcontrolstrategy>
    </internalcontrolstrategies>
    <inputdatabase servername="" databasename="" description=""/>
    <uncertaintyparameters uncertaintymodeenabled="false" numberofrunspersimulation="0"
    numberofsimulations="0"/>
    <geographicoutputdetail description="LINK"/>
    <outputemissionsbreakdownselection>
        <modelyear selected="false"/>
        <fueltype selected="false"/>
        <fuelsubtype selected="false"/>
        <emissionprocess selected="true"/>
        <onroadoffroad selected="true"/>
        <roadtype selected="false"/>
        <sourceusetype selected="false"/>
        <movesvehicletype selected="false"/>
        <onroadscc selected="false"/>
        <estimateuncertainty selected="false" numberOfIterations="2" keepSampledData="false"
        keepIterations="false"/>
        <sector selected="false"/>
        <engtechid selected="false"/>
        <hpclass selected="false"/>
```

```
        <regclassid selected="false"/>
    </outputemissionsbreakdownselection>
    <outputdatabase servername="" databasename="2030_LAPP_MicroEF_out" description=""/>
    <outputtimestep value="Hour"/>
    <outputvmtdata value="true"/>
    <outputsho value="false"/>
    <outputsh value="false"/>
    <outputshp value="false"/>
    <outputshidling value="false"/>
    <outputstarts value="false"/>
    <outputpopulation value="true"/>
    <scaleinputdatabase servername="localhost" databasename="2030_lapp_microef_in"
    description=""/>
    <pmsize value="0"/>
    <outputfactors>
        <timefactors selected="true" units="Hours"/>
        <distancefactors selected="true" units="Miles"/>
        <massfactors selected="true" units="Grams" energyunits="Million BTU"/>
    </outputfactors>
    <savedata>

    </savedata>

    <donotexecute>

    </donotexecute>

    <generatordatabase shouldsave="false" servername="" databasename="" description=""/>
        <donotperformfinalaggregation selected="false"/>
    <lookuptableflags scenarioid="" truncateoutput="true" truncateactivity="true"
    truncatebaserates="true"/>
</runspec>
```

MOVESRunID	iterationID	yearID	monthID	dayID	hourID	stateID	countyID	zoneID	linkID	pollutantID	processID	emissionQuant
1	1	2030	1	5	9	25	25025	250250	1	2	1	0.0120996
1	1	2030	1	5	9	25	25025	250250	1	2	15	5.79836E-06
1	1	2030	1	5	9	25	25025	250250	2	2	1	0.0343118
1	1	2030	1	5	9	25	25025	250250	2	2	15	1.63557E-05
1	1	2030	1	5	9	25	25025	250250	3	2	1	0.0278839
1	1	2030	1	5	9	25	25025	250250	3	2	15	0.000013265
1	1	2030	1	5	9	25	25025	250250	4	2	1	0.0967992
1	1	2030	1	5	9	25	25025	250250	4	2	15	4.64197E-05
1	1	2030	1	5	9	25	25025	250250	5	2	1	0.0158281
1	1	2030	1	5	9	25	25025	250250	5	2	15	7.5681E-06
1	1	2030	1	5	9	25	25025	250250	6	2	1	0.236011
1	1	2030	1	5	9	25	25025	250250	6	2	15	0.000112649
1	1	2030	1	5	9	25	25025	250250	7	2	1	0.0158556
1	1	2030	1	5	9	25	25025	250250	7	2	15	7.55804E-06
1	1	2030	1	5	9	25	25025	250250	8	2	1	0.0405194
1	1	2030	1	5	9	25	25025	250250	8	2	15	1.94315E-05
1	1	2030	1	5	9	25	25025	250250	9	2	1	0.0318247
1	1	2030	1	5	9	25	25025	250250	9	2	15	1.52171E-05
1	1	2030	1	5	9	25	25025	250250	10	2	1	0.0439277
1	1	2030	1	5	9	25	25025	250250	10	2	15	2.02296E-05
1	1	2030	1	5	9	25	25025	250250	11	2	1	0.0338035
1	1	2030	1	5	9	25	25025	250250	11	2	15	1.61416E-05
1	1	2030	1	5	9	25	25025	250250	12	2	1	0.0295342
1	1	2030	1	5	9	25	25025	250250	12	2	15	1.40313E-05
1	1	2030	1	5	9	25	25025	250250	13	2	1	3.45621
1	1	2030	1	5	9	25	25025	250250	13	2	15	0.00130199

Example MOVES Output File - *prepared by VHB*

This Page Intentionally Left Blank.

MOVESRunID	iterationID	yearID	monthID	dayID	hourID	stateID	countyID	zoneID	linkID	pollutantID	processID	emissionQuant
1	1	2030	1	5	9	25	25025	250250	1	2	1	0.0120996
1	1	2030	1	5	9	25	25025	250250	1	2	15	5.79836E-06
1	1	2030	1	5	9	25	25025	250250	2	2	1	0.0343118
1	1	2030	1	5	9	25	25025	250250	2	2	15	1.63557E-05
1	1	2030	1	5	9	25	25025	250250	3	2	1	0.0278839
1	1	2030	1	5	9	25	25025	250250	3	2	15	0.000013265
1	1	2030	1	5	9	25	25025	250250	4	2	1	0.0967992
1	1	2030	1	5	9	25	25025	250250	4	2	15	4.64197E-05
1	1	2030	1	5	9	25	25025	250250	5	2	1	0.0158281
1	1	2030	1	5	9	25	25025	250250	5	2	15	7.5681E-06
1	1	2030	1	5	9	25	25025	250250	6	2	1	0.236011
1	1	2030	1	5	9	25	25025	250250	6	2	15	0.000112649
1	1	2030	1	5	9	25	25025	250250	7	2	1	0.0158556
1	1	2030	1	5	9	25	25025	250250	7	2	15	7.55804E-06
1	1	2030	1	5	9	25	25025	250250	8	2	1	0.0405194
1	1	2030	1	5	9	25	25025	250250	8	2	15	1.94315E-05
1	1	2030	1	5	9	25	25025	250250	9	2	1	0.0318247
1	1	2030	1	5	9	25	25025	250250	9	2	15	1.52171E-05
1	1	2030	1	5	9	25	25025	250250	10	2	1	0.0439277
1	1	2030	1	5	9	25	25025	250250	10	2	15	2.02296E-05
1	1	2030	1	5	9	25	25025	250250	11	2	1	0.0338035
1	1	2030	1	5	9	25	25025	250250	11	2	15	1.61416E-05
1	1	2030	1	5	9	25	25025	250250	12	2	1	0.0295342
1	1	2030	1	5	9	25	25025	250250	12	2	15	1.40313E-05
1	1	2030	1	5	9	25	25025	250250	13	2	1	3.45621
1	1	2030	1	5	9	25	25025	250250	13	2	15	0.00130199

Example CAL3QHC Input File - *prepared by VHB*

This Page Intentionally Left Blank.

```
'LAPP CO ANALYSIS'  60.0  100.0  0.0  0.0  101  1  0  0  'PPM'
'1SE'  333533.0  4692742.76  1.8
'1SE'  333532.74  4692717.65  1.8
'1SE'  333528.44  4692693.02  1.8
'1SE'  333526.05  4692685.52  1.8
'1W'  333510.75  4692690.07  1.8
'1W'  333513.81  4692693.55  1.8
'1W'  333518.35  4692719.55  1.8
'1W'  333518.51  4692744.55  1.8
'1NE'  333555.4  4692767.95  1.8
'1NE'  333576.43  4692754.43  1.8
'1SE'  333571.65  4692737.29  1.8
'1SE'  333550.62  4692750.81  1.8
'1SE'  333533.2  4692756.8  1.8
'1NE'  333533.0  4692774.7  1.8
'1W'  333518.1  4692767.7  1.8
'1NE'  333532.3  4692789.4  1.8
'1NE'  333537.5  4692801.1  1.8
'1NE'  333546.0  4692808.5  1.8
'1W'  333538.8  4692821.8  1.8
'1W'  333525.0  4692809.3  1.8
'1W'  333517.6  4692792.1  1.8
'2W'  333196.71  4692836.29  1.8
'2W'  333182.02  4692856.52  1.8
'2W'  333178.53  4692862.91  1.8
'2W'  333174.26  4692887.54  1.8
'2W'  333169.99  4692912.17  1.8
'2W'  333168.01  4692923.58  1.8
'2W'  333153.28  4692943.78  1.8
'2N'  333174.83  4692945.29  1.8
'2N'  333185.68  4692928.81  1.8
'2N'  333189.95  4692904.18  1.8
'2N'  333194.22  4692879.55  1.8
'2N'  333196.2  4692868.13  1.8
'2N'  333210.89  4692847.9  1.8
'2N'  333232.68  4692843.91  1.8
'2N'  333257.19  4692856.18  1.8
'2N'  333277.84  4692842.09  1.8
'2N'  333298.49  4692828.0  1.8
'2N'  333319.14  4692813.91  1.8
'2N'  333339.8  4692799.82  1.8
'2E'  333339.8  4692779.24  1.8
'2E'  333319.15  4692793.33  1.8
'2E'  333298.5  4692807.42  1.8
'2E'  333277.85  4692821.51  1.8
'2E'  333257.19  4692835.6  1.8
'2E'  333252.88  4692838.54  1.8
'2E'  333233.6  4692822.63  1.8
'2E'  333237.71  4692811.36  1.8
'2E'  333257.18  4692795.68  1.8
'2E'  333276.64  4692779.99  1.8
'2E'  333290.07  4692769.16  1.8
'2E'  333311.74  4692756.68  1.8
'2S'  333311.8  4692740.94  1.8
'2S'  333290.14  4692753.43  1.8
'2S'  333281.95  4692758.24  1.8
'2S'  333262.49  4692773.93  1.8
'2S'  333243.02  4692789.61  1.8
'2W'  333195.94  4692742.81  1.8
'2W'  333193.65  4692750.25  1.8
'2W'  333191.6  4692775.17  1.8
'2W'  333191.54  4692784.88  1.8
'2W'  333201.01  4692808.01  1.8
'2S'  333224.45  4692784.8  1.8
```

```
'2S'  333217.97  4692769.59  1.8
'2S'  333222.48  4692745.0  1.8
'2E'  333228.9  4692818.6  1.8
'2N'  333220.9  4692834.7  1.8
'2W'  333206.5  4692822.4  1.8
'2S'  333230.7  4692799.2  1.8
'3NW'  333104.37  4693609.0  1.8
'3NW'  333121.02  4693627.65  1.8
'3NW'  333137.67  4693646.3  1.8
'3NW'  333154.31  4693664.95  1.8
'3E'  333165.2  4693658.08  1.8
'3E'  333148.56  4693639.43  1.8
'3E'  333131.91  4693620.78  1.8
'3S'  333097.84  4693584.06  1.8
'3S'  333077.77  4693569.16  1.8
'3S'  333063.47  4693558.56  1.8
'3S'  333046.67  4693540.05  1.8
'3NW'  333042.96  4693555.31  1.8
'3NW'  333055.22  4693568.62  1.8
'3NW'  333075.29  4693583.52  1.8
'3E'  333188.2  4693543.21  1.8
'3E'  333206.86  4693526.58  1.8
'3E'  333225.53  4693509.95  1.8
'3S'  333220.15  4693496.93  1.8
'3S'  333201.48  4693513.56  1.8
'3S'  333182.81  4693530.19  1.8
'3S'  333164.15  4693546.82  1.8
'3S'  333145.48  4693563.46  1.8
'3S'  333126.82  4693580.09  1.8
'3E'  333134.58  4693601.31  1.8
'3E'  333153.35  4693584.8  1.8
'3E'  333163.93  4693575.34  1.8
'3E'  333178.97  4693555.37  1.8
'3E'  333128.9  4693617.1  1.8
'3S'  333109.3  4693595.4  1.8
'3E'  333118.7  4693605.6  1.8
'3E'  333120.6  4693607.8  1.8
'3E'  333122.7  4693601.9  1.8
'BUILD'  41  1  0  'C'
2  1
'TERME_WBAPP_Q'  'AG'  333539.8  4692768.9  333615.5  4692720.4  0.0  3.7  1
120  70  2  240  3.46  1600  1  3
1  4
'TERME_SBAPP_FF'  'AG'  333558.1  4692818.9  333542.5  4692815.3  710  1.22  0.0  14.5
1
'TERME_SBAPP_FF'  'AG'  333542.5  4692815.3  333531.4  4692805.6  710  1.22  0.0  14.5
1
'TERME_SBAPP_FF'  'AG'  333531.4  4692805.6  333524.9  4692790.9  710  1.22  0.0  14.5
1
'TERME_SBAPP_FF'  'AG'  333524.9  4692790.9  333525.9  4692767.8  710  1.22  0.0  14.5
1  3
'TERME_SBDEP_FF'  'AG'  333525.9  4692767.8  333525.6  4692718.9  895  1.13  0.0  14.5
1
'TERME_SBDEP_FF'  'AG'  333525.6  4692718.9  333520.6  4692690.3  895  1.13  0.0  14.5
1
'TERME_SBDEP_FF'  'AG'  333520.6  4692690.3  333499.7  4692666.5  895  1.13  0.0  14.5
1  2
'TERME_WBAPP_FF'  'AG'  333525.7  4692767.8  333550.8  4692760.8  295  1.72  0.0  17.0
1
'TERME_WBAPP_FF'  'AG'  333550.8  4692760.8  333618.3  4692717.4  295  1.72  0.0  17.0
1  1
'SERVICEN@PRESCOTT_FF'  'AG'  333109.11  4693604.77  333193.76  4693699.61  765  1.23  0.0  12.7
1  3
'SERVICES@PRESCOTT_FF'  'AG'  333109.11  4693604.77  333093.97  4693589.28  855  1.18  0.0  13.0
```

```
1
'SERVICES@PRESCOTT_FF'  'AG'  333093.97  4693589.28  333059.09  4693563.4  855  1.18  0.0  13.0
1
'SERVICES@PRESCOTT_FF'  'AG'  333059.09  4693563.4  332997.35  4693495.42  855  1.18  0.0  13.0
1  1
'PRESCOTTE@SERVICE_FF'  'AG'  333109.11  4693604.77  333355.23  4693385.48  215  1.15  0.0  13.3
1  3
'PRESCOTTRT@SERVICE_F'  'AG'  333122.14  4693619.36  333130.08  4693598.21  55  1.13  0.0  10.6
1
'PRESCOTTRT@SERVICE_F'  'AG'  333130.08  4693598.21  333159.7  4693572.15  55  1.13  0.0  10.6
1
'PRESCOTTRT@SERVICE_F'  'AG'  333159.7  4693572.15  333186.2  4693536.96  55  1.13  0.0  10.6
1  3
'SERVICEN@HOTEL_FF'  'AG'  333218.8  4692821.44  333187.55  4692864.47  870  1.23  0.0  18.3
1
'SERVICEN@HOTEL_FF'  'AG'  333187.55  4692864.47  333176.66  4692927.25  870  1.23  0.0  18.3
1
'SERVICEN@HOTEL_FF'  'AG'  333176.66  4692927.25  333064.32  4693081.29  870  1.23  0.0  18.3
1  2
'TERMEN@HOTEL_FF'  'AG'  333218.8  4692821.44  333252.4  4692849.16  560  1.18  0.0  17.0
1
'TERMEN@HOTEL_FF'  'AG'  333252.4  4692849.16  333344.59  4692786.26  560  1.18  0.0  17.0
1  2
'SERVICES@HOTEL_FF'  'AG'  333213.98  4692821.76  333286.22  4692763.53  255  0.76  0.0  13.6
1
'SERVICES@HOTEL_FF'  'AG'  333286.22  4692763.53  333423.5  4692684.43  255  0.76  0.0  13.6
1  4
'HOTELDEP@SERVICE_FF'  'AG'  333215.64  4692825.8  333197.83  4692782.3  410  1.16  0.0  13.6
1
'HOTELDEP@SERVICE_FF'  'AG'  333197.83  4692782.3  333200.43  4692750.81  410  1.16  0.0  13.6
1
'HOTELDEP@SERVICE_FF'  'AG'  333200.43  4692750.81  333210.32  4692721.26  410  1.16  0.0  13.6
1
'HOTELDEP@SERVICE_FF'  'AG'  333210.32  4692721.26  333277.09  4692646.2  410  1.16  0.0  13.6
1  3
'HOTELAPP@SERICE_FF'  'AG'  333228.0  4692810.46  333210.91  4692770.37  615  1.09  0.0  13.6
1
'HOTELAPP@SERICE_FF'  'AG'  333210.91  4692770.37  333220.1  4692720.29  615  1.09  0.0  13.6
1
'HOTELAPP@SERICE_FF'  'AG'  333220.1  4692720.29  333282.02  4692650.89  615  1.09  0.0  13.6
2  1
'PRESCOTTLT@SERVICE_Q'  'AG'  333122.14  4693596.63  333324.81  4693416.15  0.0  3.6  1
120  70  2  90  3.46  1600  1  3
2  1
'PRESCOTTRT@SERVICE_Q'  'AG'  333127.1  4693602.58  333167.19  4693563.42  0.0  4.6  1
120  70  2  55  3.46  1600  1  3
2  2
'SERVICESB@HOTEL_Q'  'AG'  333205.85  4692834.13  333188.54  4692859.6  0.0  7.3  1
65  25  2  315  3.46  3200  2  3
2
'SERVICESB@HOTEL_Q'  'AG'  333188.54  4692859.6  333177.71  4692907.51  0.0  7.3  1
65  25  2  315  3.46  3200  2  3
2  2
'HOTELAPP@SERVICE_Q'  'AG'  333221.13  4692794.36  333210.91  4692770.37  0.0  7.3  1
65  25  2  615  3.46  3200  2  3
2
'HOTELAPP@SERVICE_Q'  'AG'  333210.91  4692770.37  333216.9  4692737.7  0.0  7.3  1
65  25  2  615  3.46  3200  2  3
2  2
'TERMEAPP@HOTEL_Q'  'AG'  333232.67  4692837.33  333248.05  4692849.41  0.0  5.3  1
65  52  2  170  3.46  1600  2  3
2
'TERMEAPP@HOTEL_Q'  'AG'  333248.05  4692849.41  333265.81  4692845.0  0.0  5.3  1
65  52  2  170  3.46  1600  2  3
```

```
2  1
'SERVICENB@HOTEL_Q'  'AG'  333238.02  4692802.39  333286.22  4692763.53  0.0  7.3  1
65  40  2  255  3.46  3200  2  3
1.0  0  4  1000.0  0.0  'Y'  10  0  35
** BREEZE
** PROJECTN  0 104 7 -177 0 0.9996 500000 0
** MAPLAYER H:\RDS\LAPP\IMGS\PROJAERIAL.JPG TERMEAERIAL 3 UNKNOWN UNKNOWN 1 0 0 0 0 0 0 0 0 0 0
16777215 0 0 1 1 332984.890546 333643.690546 4692636.79743 4693706.89743
** MAPLAYER H:\RDS\LAPP\IMGS\TERMEGARAGEM.JPG TERMEPLANS 3 UNKNOWN UNKNOWN 1 0 0 0 0 0 0 0 0 0
0 16777215 0 0 1 1 333375.599533 333887.404884 4692460.21525 4692913.18058
** OUTFILE  H:\RDS\LAPP\BuildRdwys_LAPP.lst
** RAWFILE
** PERCENT
** PLOT
```

This Page Intentionally Left Blank.

Example CAL3QHC Output File - *prepared by VHB*

This Page Intentionally Left Blank.

```
1                     CAL3QHC - (DATED 95221)

                CAL3QHC  PC (32 BIT) VERSION 3.0.0
               (C) COPYRIGHT 1993-2000, TRINITY CONSULTANTS

 Run Began on  2/21/2019 at 13:49:31

      JOB: LAPP CO ANALYSIS                                   RUN:
      BUILD

      DATE : 02/21/   0
      TIME : 13:49:31

         The MODE flag has been set to C for calculating CO averages.

       SITE & METEOROLOGICAL VARIABLES
       -------------------------------
       VS =   0.0 CM/S       VD =   0.0 CM/S       Z0 = 100. CM
        U =  1.0 M/S         CLAS =   4  (D)     ATIM =  60. MINUTES     MIXH =  1000. M   AMB
        =  0.0 PPM

       LINK VARIABLES
       --------------
         LINK DESCRIPTION     *         LINK COORDINATES (M)           *    LENGTH  BRG TYPE
         VPH    EF      H   W    V/C QUEUE
                              *   X1        Y1        X2        Y2     *     (M)
                              (DEG)            (G/MI)   (M) (M)       (VEH)

      ------------------------*----------------------------------------*------------------------
      ---------------------------------
       1. TERME_WBAPP_Q       * 333539.8  ********  333563.4  ******** *      28.   123.
       AG      5. 100.0   0.0  3.7 0.39   4.7
       2. TERME_SBAPP_FF      * 333558.1  ********  333542.5  ******** *      16.   257. AG
       710.   1.2   0.0 14.5
       3. TERME_SBAPP_FF      * 333542.5  ********  333531.4  ******** *      15.   228. AG
       710.   1.2   0.0 14.5
       4. TERME_SBAPP_FF      * 333531.4  ********  333524.9  ******** *      16.   204. AG
       710.   1.2   0.0 14.5
       5. TERME_SBAPP_FF      * 333524.9  ********  333525.9  ******** *      23.   178. AG
       710.   1.2   0.0 14.5
       6. TERME_SBDEP_FF      * 333525.9  ********  333525.6  ******** *      49.   180. AG
       895.   1.1   0.0 14.5
       7. TERME_SBDEP_FF      * 333525.6  ********  333520.6  ******** *      29.   190. AG
       895.   1.1   0.0 14.5
       8. TERME_SBDEP_FF      * 333520.6  ********  333499.7  ******** *      32.   221. AG
       895.   1.1   0.0 14.5
       9. TERME_WBAPP_FF      * 333525.7  ********  333550.8  ******** *      26.   106. AG
       295.   1.7   0.0 17.0
      10. TERME_WBAPP_FF      * 333550.8  ********  333618.3  ******** *      80.   123. AG
      295.   1.7   0.0 17.0
      11. SERVICEN@PRESCOTT_FF* 333109.1  ********  333193.8  ******** *     127.    42. AG
      765.   1.2   0.0 12.7
      12. SERVICES@PRESCOTT_FF* 333109.1  ********  333094.0  ******** *      22.   224. AG
      855.   1.2   0.0 13.0
      13. SERVICES@PRESCOTT_FF* 333094.0  ********  333059.1  ******** *      44.   233. AG
      855.   1.2   0.0 13.0
      14. SERVICES@PRESCOTT_FF* 333059.1  ********  332997.3  ******** *      92.   222. AG
      855.   1.2   0.0 13.0
      15. PRESCOTTE@SERVICE_FF* 333109.1  ********  333355.2  ******** *     330.   132. AG
      215.   1.1   0.0 13.3
      16. PRESCOTTRT@SERVICE_F* 333122.1  ********  333130.1  ******** *      23.   160. AG
      55.   1.1   0.0 10.6
      17. PRESCOTTRT@SERVICE_F* 333130.1  ********  333159.7  ******** *      39.   131. AG
      55.   1.1   0.0 10.6
```

```
18. PRESCOTTRT@SERVICE_F* 333159.7  ********  333186.2  ******** *     44.   143. AG
55.   1.1   0.0 10.6
19. SERVICEN@HOTEL_FF   * 333218.8  ********  333187.6  ******** *     53.   324. AG
870.   1.2   0.0 18.3
20. SERVICEN@HOTEL_FF   * 333187.6  ********  333176.7  ******** *     63.   350. AG
870.   1.2   0.0 18.3
21. SERVICEN@HOTEL_FF   * 333176.7  ********  333064.3  ******** *    191.   324. AG
870.   1.2   0.0 18.3
22. TERMEN@HOTEL_FF     * 333218.8  ********  333252.4  ******** *     43.    51. AG
560.   1.2   0.0 17.0
23. TERMEN@HOTEL_FF     * 333252.4  ********  333344.6  ******** *    111.   124. AG
560.   1.2   0.0 17.0
24. SERVICES@HOTEL_FF   * 333214.0  ********  333286.2  ******** *     93.   129. AG
255.   0.8   0.0 13.6
25. SERVICES@HOTEL_FF   * 333286.2  ********  333423.5  ******** *    158.   120. AG
255.   0.8   0.0 13.6
26. HOTELDEP@SERVICE_FF * 333215.6  ********  333197.8  ******** *     47.   202. AG
410.   1.2   0.0 13.6
27. HOTELDEP@SERVICE_FF * 333197.8  ********  333200.4  ******** *     32.   175. AG
410.   1.2   0.0 13.6
28. HOTELDEP@SERVICE_FF * 333200.4  ********  333210.3  ******** *     31.   161. AG
410.   1.2   0.0 13.6
29. HOTELDEP@SERVICE_FF * 333210.3  ********  333277.1  ******** *    101.   139. AG
410.   1.2   0.0 13.6
30. HOTELAPP@SERICE_FF  * 333228.0  ********  333210.9  ******** *     43.   203. AG
615.   1.1   0.0 13.6
31. HOTELAPP@SERICE_FF  * 333210.9  ********  333220.1  ******** *     51.   170. AG
615.   1.1   0.0 13.6
32. HOTELAPP@SERICE_FF  * 333220.1  ********  333282.0  ******** *     93.   138. AG
615.   1.1   0.0 13.6
33. PRESCOTTLT@SERVICE_Q* 333122.1  ********  333130.0  ******** *     11.   132.
AG      5. 100.0   0.0  3.6 0.15   1.8
34. PRESCOTTRT@SERVICE_Q* 333127.1  ********  333131.7  ******** *      6.   134.
AG      5. 100.0   0.0  4.6 0.09   1.1
35. SERVICESB@HOTEL_Q   * 333205.8  ********  333198.5  ******** *     13.   326.
AG      4. 100.0   0.0  7.3 0.18   2.2
36. SERVICESB@HOTEL_Q   * 333188.5  ********  333185.7  ******** *     13.   347.
AG      4. 100.0   0.0  7.3 0.18   2.2
37. HOTELAPP@SERVICE_Q  * 333221.1  ********  333211.1  ******** *     26.   203.
AG      4. 100.0   0.0  7.3 0.35   4.3
38. HOTELAPP@SERVICE_Q  * 333210.9  ********  333215.5  ******** *     26.   170.
AG      4. 100.0   0.0  7.3 0.35   4.3
39. TERMEAPP@HOTEL_Q    * 333232.7  ********  333245.6  ******** *     16.    52.
AG      7. 100.0   0.0  5.3 0.77   2.7
40. TERMEAPP@HOTEL_Q    * 333248.1  ********  333264.0  ******** *     16.   104.
AG      7. 100.0   0.0  5.3 0.77   2.7
41. SERVICENB@HOTEL_Q   * 333238.0  ********  333251.2  ******** *     17.   129.
AG      6. 100.0   0.0  7.3 0.25   2.8
```

FF

```
           PAGE  2
JOB: LAPP CO ANALYSIS                                     RUN:
BUILD

DATE : 02/21/   0
TIME : 13:49:31

 ADDITIONAL QUEUE LINK PARAMETERS
 --------------------------------
   LINK DESCRIPTION     *    CYCLE    RED     CLEARANCE  APPROACH  SATURATION   IDLE
   SIGNAL   ARRIVAL
                        *    LENGTH   TIME    LOST TIME    VOL     FLOW RATE   EM FAC
                        TYPE     RATE
                        *     (SEC)   (SEC)    (SEC)      (VPH)      (VPH)    (gm/hr)
```

```
------------------------*----------------------------------------------------------------------------
--------------
 1. TERME_WBAPP_Q       *     120        70        2.0        240        1600        3.46
 1         3
33. PRESCOTTLT@SERVICE_Q*     120        70        2.0         90        1600        3.46
1         3
34. PRESCOTTRT@SERVICE_Q*     120        70        2.0         55        1600        3.46
1         3
35. SERVICESB@HOTEL_Q   *      65        25        2.0        315        3200        3.46
2         3
36. SERVICESB@HOTEL_Q   *      65        25        2.0        315        3200        3.46
2         3
37. HOTELAPP@SERVICE_Q  *      65        25        2.0        615        3200        3.46
2         3
38. HOTELAPP@SERVICE_Q  *      65        25        2.0        615        3200        3.46
2         3
39. TERMEAPP@HOTEL_Q    *      65        52        2.0        170        1600        3.46
2         3
40. TERMEAPP@HOTEL_Q    *      65        52        2.0        170        1600        3.46
2         3
41. SERVICENB@HOTEL_Q   *      65        40        2.0        255        3200        3.46
2         3

 RECEPTOR LOCATIONS
 ------------------
                        *          COORDINATES (M)          *
   RECEPTOR             *      X           Y          Z     *
-------------------------*-----------------------------------*
 1. 1SE                 *    333533.0   ********       1.8   *
 2. 1SE                 *    333532.8   ********       1.8   *
 3. 1SE                 *    333528.4   ********       1.8   *
 4. 1SE                 *    333526.1   ********       1.8   *
 5. 1W                  *    333510.8   ********       1.8   *
 6. 1W                  *    333513.8   ********       1.8   *
 7. 1W                  *    333518.3   ********       1.8   *
 8. 1W                  *    333518.5   ********       1.8   *
 9. 1NE                 *    333555.4   ********       1.8   *
10. 1NE                 *    333576.4   ********       1.8   *
11. 1SE                 *    333571.7   ********       1.8   *
12. 1SE                 *    333550.6   ********       1.8   *
13. 1SE                 *    333533.2   ********       1.8   *
14. 1NE                 *    333533.0   ********       1.8   *
15. 1W                  *    333518.1   ********       1.8   *
16. 1NE                 *    333532.3   ********       1.8   *
17. 1NE                 *    333537.5   ********       1.8   *
18. 1NE                 *    333546.0   ********       1.8   *
19. 1W                  *    333538.8   ********       1.8   *
20. 1W                  *    333525.0   ********       1.8   *
21. 1W                  *    333517.6   ********       1.8   *
22. 2W                  *    333196.7   ********       1.8   *
23. 2W                  *    333182.0   ********       1.8   *
24. 2W                  *    333178.5   ********       1.8   *
25. 2W                  *    333174.2   ********       1.8   *
26. 2W                  *    333170.0   ********       1.8   *
27. 2W                  *    333168.0   ********       1.8   *
28. 2W                  *    333153.3   ********       1.8   *
29. 2N                  *    333174.8   ********       1.8   *
30. 2N                  *    333185.7   ********       1.8   *
31. 2N                  *    333189.9   ********       1.8   *
32. 2N                  *    333194.2   ********       1.8   *
33. 2N                  *    333196.2   ********       1.8   *
34. 2N                  *    333210.9   ********       1.8   *
35. 2N                  *    333232.7   ********       1.8   *
```

```
          PAGE  3
JOB: LAPP CO ANALYSIS                                 RUN:
BUILD

DATE : 02/21/   0
TIME : 13:49:31


 RECEPTOR LOCATIONS
 ------------------
                        *          COORDINATES (M)           *
   RECEPTOR             *      X           Y          Z      *
------------------------*------------------------------------*
36. 2N                  *    333257.2   ********       1.8   *
37. 2N                  *    333277.8   ********       1.8   *
38. 2N                  *    333298.5   ********       1.8   *
39. 2N                  *    333319.1   ********       1.8   *
40. 2N                  *    333339.8   ********       1.8   *
41. 2E                  *    333339.8   ********       1.8   *
42. 2E                  *    333319.2   ********       1.8   *
43. 2E                  *    333298.5   ********       1.8   *
44. 2E                  *    333277.8   ********       1.8   *
45. 2E                  *    333257.2   ********       1.8   *
46. 2E                  *    333252.9   ********       1.8   *
47. 2E                  *    333233.6   ********       1.8   *
48. 2E                  *    333237.7   ********       1.8   *
49. 2E                  *    333257.2   ********       1.8   *
50. 2E                  *    333276.6   ********       1.8   *
51. 2E                  *    333290.1   ********       1.8   *
52. 2E                  *    333311.8   ********       1.8   *
53. 2S                  *    333311.8   ********       1.8   *
54. 2S                  *    333290.1   ********       1.8   *
55. 2S                  *    333281.9   ********       1.8   *
56. 2S                  *    333262.5   ********       1.8   *
57. 2S                  *    333243.0   ********       1.8   *
58. 2W                  *    333195.9   ********       1.8   *
59. 2W                  *    333193.7   ********       1.8   *
60. 2W                  *    333191.6   ********       1.8   *
61. 2W                  *    333191.5   ********       1.8   *
62. 2W                  *    333201.0   ********       1.8   *
63. 2S                  *    333224.4   ********       1.8   *
64. 2S                  *    333218.0   ********       1.8   *
65. 2S                  *    333222.5   ********       1.8   *
66. 2E                  *    333228.9   ********       1.8   *
67. 2N                  *    333220.9   ********       1.8   *
68. 2W                  *    333206.5   ********       1.8   *
69. 2S                  *    333230.7   ********       1.8   *
70. 3NW                 *    333104.4   ********       1.8   *
71. 3NW                 *    333121.0   ********       1.8   *
72. 3NW                 *    333137.7   ********       1.8   *
73. 3NW                 *    333154.3   ********       1.8   *
74. 3E                  *    333165.2   ********       1.8   *
75. 3E                  *    333148.6   ********       1.8   *
76. 3E                  *    333131.9   ********       1.8   *
77. 3S                  *    333097.8   ********       1.8   *
78. 3S                  *    333077.8   ********       1.8   *
79. 3S                  *    333063.5   ********       1.8   *
80. 3S                  *    333046.7   ********       1.8   *
81. 3NW                 *    333043.0   ********       1.8   *
82. 3NW                 *    333055.2   ********       1.8   *
83. 3NW                 *    333075.3   ********       1.8   *
84. 3E                  *    333188.2   ********       1.8   *
85. 3E                  *    333206.9   ********       1.8   *
```

```
                 PAGE  4
      JOB: LAPP CO ANALYSIS                                      RUN:
      BUILD

      DATE : 02/21/   0
      TIME : 13:49:31


       RECEPTOR LOCATIONS
       ------------------
                             *            COORDINATES (M)            *
         RECEPTOR            *       X           Y           Z       *
     ------------------------*-----------------------------------*
    86. 3E                   *    333225.5   ********       1.8   *
    87. 3S                   *    333220.2   ********       1.8   *
    88. 3S                   *    333201.5   ********       1.8   *
    89. 3S                   *    333182.8   ********       1.8   *
    90. 3S                   *    333164.2   ********       1.8   *
    91. 3S                   *    333145.5   ********       1.8   *
    92. 3S                   *    333126.8   ********       1.8   *
    93. 3E                   *    333134.6   ********       1.8   *
    94. 3E                   *    333153.3   ********       1.8   *
    95. 3E                   *    333163.9   ********       1.8   *
    96. 3E                   *    333179.0   ********       1.8   *
    97. 3E                   *    333128.9   ********       1.8   *
    98. 3S                   *    333109.3   ********       1.8   *
    99. 3E                   *    333118.7   ********       1.8   *
   100. 3E                   *    333120.6   ********       1.8   *
   101. 3E                   *    333122.7   ********       1.8   *

                 PAGE  5
      JOB: LAPP CO ANALYSIS                                      RUN:
      BUILD

       MODEL RESULTS
       -------------

       REMARKS : In search of the angle corresponding to
                 the maximum concentration, only the first
                 angle, of the angles with same maximum
                 concentrations, is indicated as maximum.

 WIND ANGLE RANGE:   0.-350.

 WIND  * CONCENTRATION
 ANGLE *      (PPM)
 (DEGR)* REC1  REC2  REC3  REC4  REC5  REC6  REC7  REC8  REC9  REC10 REC11 REC12 REC13 REC14
 REC15 REC16 REC17 REC18 REC19 REC20

 ------*------------------------------------------------------------------------------------------
 ------------------------------
   0.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0
  10.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  20.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  30.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  40.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  50.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  60.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

```
 0.0   0.0   0.0   0.0   0.0   0.0
 70.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 80.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 90.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
100.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
110.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
120.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
130.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
140.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
150.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
160.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
170.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
180.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
190.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
200.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
210.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
220.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
230.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
240.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
250.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
260.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
270.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
280.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
290.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
300.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
310.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
320.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
330.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
340.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
350.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0

------*-----------------------------------------------------------------------------------------
------------------------------
MAX   *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
```

```
 DEGR. *    0     0     0     0     0     0     0     0     0     0     0     0     0     0
 0     0     0     0     0     0

FF
                 PAGE  6
      JOB: LAPP CO ANALYSIS                                     RUN:
      BUILD

       MODEL RESULTS
       -------------

       REMARKS : In search of the angle corresponding to
                 the maximum concentration, only the first
                 angle, of the angles with same maximum
                 concentrations, is indicated as maximum.

 WIND ANGLE RANGE:   0.-350.

 WIND  * CONCENTRATION
 ANGLE *      (PPM)
 (DEGR)* REC21 REC22 REC23 REC24 REC25 REC26 REC27 REC28 REC29 REC30 REC31 REC32 REC33 REC34
 REC35 REC36 REC37 REC38 REC39 REC40

 ------*---------------------------------------------------------------------------------------
 ------------------------------
   0.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0
  10.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  20.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  30.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  40.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  50.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  60.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  70.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  80.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  90.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
 100.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 110.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 120.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 130.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 140.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 150.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 160.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 170.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 180.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 190.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

```
0.0   0.0   0.0   0.0   0.0   0.0
200.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
210.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
220.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
230.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
240.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
250.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
260.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
270.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
280.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
290.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
300.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
310.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.1   0.1   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
320.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.1   0.1   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
330.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.1   0.1   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
340.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.1   0.1   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
350.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0

------*-----------------------------------------------------------------------------------------
------------------------------
MAX   *   0.0   0.0   0.0   0.0   0.0   0.0   0.1   0.1   0.1   0.1   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
DEGR. *    0     0     0     0     0     0   330   330   310   310     0     0     0     0
0     0     0     0     0     0

FF
                  PAGE  7
     JOB: LAPP CO ANALYSIS                                  RUN:
     BUILD

      MODEL RESULTS
      -------------

      REMARKS : In search of the angle corresponding to
                the maximum concentration, only the first
                angle, of the angles with same maximum
                concentrations, is indicated as maximum.

WIND ANGLE RANGE:   0.-350.

WIND  * CONCENTRATION
ANGLE *      (PPM)
(DEGR)* REC41 REC42 REC43 REC44 REC45 REC46 REC47 REC48 REC49 REC50 REC51 REC52 REC53 REC54
REC55 REC56 REC57 REC58 REC59 REC60

------*-----------------------------------------------------------------------------------------
------------------------------
  0.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

```
  0.0   0.0   0.0   0.0   0.0   0.0
 10.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 20.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 30.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 40.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 50.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 60.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 70.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 80.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 90.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
100.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
110.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
120.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
130.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
140.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
150.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
160.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
170.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
180.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
190.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
200.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
210.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
220.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
230.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
240.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
250.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
260.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
270.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
280.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
290.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
300.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
310.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
320.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

```
0.0   0.0   0.0   0.0   0.0   0.0
330.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
340.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
350.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0

------*---------------------------------------------------------------------------------------
-------------------------------
MAX   *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
DEGR. *    0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0

FF
                 PAGE  8
     JOB: LAPP CO ANALYSIS                                         RUN:
     BUILD

      MODEL RESULTS
      -------------

      REMARKS : In search of the angle corresponding to
                the maximum concentration, only the first
                angle, of the angles with same maximum
                concentrations, is indicated as maximum.

WIND ANGLE RANGE:   0.-350.

WIND  * CONCENTRATION
ANGLE *      (PPM)
(DEGR)* REC61 REC62 REC63 REC64 REC65 REC66 REC67 REC68 REC69 REC70 REC71 REC72 REC73 REC74
REC75 REC76 REC77 REC78 REC79 REC80

------*---------------------------------------------------------------------------------------
-------------------------------
  0.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
 10.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 20.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 30.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.1   0.1   0.0   0.0   0.0   0.0
 40.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 50.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.1   0.1   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 60.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.1   0.1   0.1   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 70.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 80.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 90.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
100.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
110.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
120.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
130.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

```
 0.0   0.0   0.0   0.0   0.0   0.0
 140.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 150.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 160.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 170.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 180.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 190.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 200.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 210.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.1   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 220.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 230.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.1   0.0
 240.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.1
 0.0   0.0   0.0   0.0   0.1   0.1
 250.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 260.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 270.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 280.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 290.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 300.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 310.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 320.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 330.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 340.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 350.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0

 ------*-----------------------------------------------------------------------------------------
 -------------------------------
 MAX   *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.1   0.1   0.1   0.1   0.1
 0.1   0.1   0.0   0.0   0.1   0.1
 DEGR. *    0     0     0     0     0     0     0     0     0    50    50    60   210   240
 30    30     0     0   230   240

FF
                PAGE  9
      JOB: LAPP CO ANALYSIS                                    RUN:
      BUILD

       MODEL RESULTS
       -------------

       REMARKS : In search of the angle corresponding to
                 the maximum concentration, only the first
                 angle, of the angles with same maximum
```

```
                 concentrations, is indicated as maximum.

 WIND ANGLE RANGE:   0.-350.

 WIND  * CONCENTRATION
 ANGLE *      (PPM)
 (DEGR)* REC81 REC82 REC83 REC84 REC85 REC86 REC87 REC88 REC89 REC90 REC91 REC92 REC93 REC94
 REC95 REC96 REC97 REC98 REC99 RE100

 ------*------------------------------------------------------------------------------------
 ------------------------------
   0.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0
  10.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  20.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  30.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.1   0.0   0.1   0.1
  40.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  50.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  60.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  70.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  80.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
  90.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0
 100.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 110.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 120.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 130.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 140.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 150.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 160.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 170.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 180.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 190.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 200.  *   0.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 210.  *   0.1   0.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 220.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 230.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 240.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 250.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 0.0   0.0   0.0   0.0   0.0   0.0
 260.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

```
0.0   0.0   0.0   0.0   0.0   0.0
270.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
280.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
290.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
300.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
310.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
320.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
330.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
340.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0
350.  *   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0

------*-------------------------------------------------------------------------------------
-------------------------------
MAX   *   0.1   0.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.1   0.0   0.1   0.1
DEGR. *  200   210     0     0     0     0     0     0     0     0     0     0     0     0
0     0    30     0    30    30

FF
                 PAGE 10
     JOB: LAPP CO ANALYSIS                                    RUN:
     BUILD

      MODEL RESULTS
      -------------

      REMARKS : In search of the angle corresponding to
                the maximum concentration, only the first
                angle, of the angles with same maximum
                concentrations, is indicated as maximum.

WIND ANGLE RANGE:   0.-350.

WIND  * CONCENTRATION
ANGLE *      (PPM)
(DEGR)* RE101
------*------
  0.  *   0.0
 10.  *   0.0
 20.  *   0.0
 30.  *   0.0
 40.  *   0.0
 50.  *   0.0
 60.  *   0.0
 70.  *   0.0
 80.  *   0.0
 90.  *   0.0
100.  *   0.0
110.  *   0.0
120.  *   0.0
130.  *   0.0
140.  *   0.0
150.  *   0.0
160.  *   0.0
170.  *   0.0
```

```
180.  *   0.0
190.  *   0.0
200.  *   0.0
210.  *   0.0
220.  *   0.0
230.  *   0.0
240.  *   0.0
250.  *   0.0
260.  *   0.0
270.  *   0.0
280.  *   0.0
290.  *   0.0
300.  *   0.0
310.  *   0.0
320.  *   0.0
330.  *   0.0
340.  *   0.0
350.  *   0.0
------*------
MAX   *   0.0
DEGR. *    0

THE HIGHEST CONCENTRATION OF    0.10 PPM OCCURRED AT RECEPTOR REC75.
```

Energy Assessment - *prepared by WSP*

This Page Intentionally Left Blank.

Massport

LAPP - Logan 5000 Economy Parking Structure-BASE CASE

Revision 1

Date 3/26/2019

Electrical Load Calculations

Normal Power Load

No.	Load Description	No. of Units	Unit of Measure	Unit Load Watt or kW		Full Load Amperes (A)	Connected Load, KVA	Connected Load, KW	Diversity Factor	Diversity Load, KVA	Diversity Load, KW	Comments/Remarks/Assumptions	Annual Consumption, KWh
						CONNECTED LOAD			DIVERSIFIED LOAD				
	LIGHTING												
LTG-001	Lighting (Garage)	580,000	Area-SF	0.19	Watt/SF		122.4	110.20	75%	91.83	82.65		724,014.00
LTG-002	Lighting (Garage Existing)	573,125	Area-SF	0.152	Watt/SF		96.7	87.00	100%	96.67	87.00	Existing Calc	762,123.29
LTG-003	Lighting (Mechanical / Electrical Spaces)	1,000	Area-SF	0.8	Watt/SF		0.9	0.80	50%	0.44	0.40		3,504.00
LTG-004	Lighting (Offices, Conference Rooms, Toilets, Corridors, etc.)	-	Area-SF	0.8	Watt/SF				80%	0.00	0.00	No Planned Office Space	
LTG-005	Lighting (Roadway)	-	LS	0	KVA				65%	0.00	0.00	No Planned Roadway Lighting served from Garage	
LTG-006	Lighting (Linear Façade)	-	LF	6	Watt/LF		0.0	0.00	65%	0.00	0.00	No Planned Façade Lighting	
LTG-007	Lighting (Elevator Lobbies)	-	Area-SF	1.6	Watt/SF		0.0	0.00	100%	0.00	0.00	No Planned Elevator Lobbies	
	GARAGE LIGHTING SUB-TOTAL ELECTRICAL LOAD						*220.00*	*198.00*		*188.94*	*170.05*		1,489,641.29
	GENERAL POWER												
GEN-001	Receptacles (Garage) 1st 10KVA	322	EA	0.18	kW		11.1	10.00	10%	1.11	1.00	1st 10KVA at 100%, assumed 2 per 60' x 60' bay.	8,760.00
GEN-002	Receptacles (Garage) Remaining						53.3	48.00	10%	5.33	4.80	Remaining at 50%	42,048.00
GEN-003	Receptacles (Ancillary Rooms) 1st 10KVA	50	EA	0.18	kW		10.0	9.00	10%	1.00	0.90	1st 10KVA at 100%, Estimated at 50 total.	7,884.00
GEN-004	Receptacles (Ancillary Rooms) Remaining						0.0	0.00	10%	0.00	0.00	Remaining at 50%	-
													-
GEN-005	Receptacles (Elevator Lobbies) 1st 10KVA	-	EA	0.18	kW		11.1	10.00	10%	1.11	1.00	1st 10KVA at 100%, Estimated at 70 total.	8,760.00
GEN-006	Receptacles (Elevator Lobbies) Remaining						0.0	-10.00	10%	0.00	-1.00	Remaining at 50%	(8,760.00)
													-
	IDF Rooms												-
GEN-007	IDF-01	1	EA	60	A		21.6	19.43	50%	10.80	9.72		85,109.36
													-
GEN-011	Electrical Vehicle Chargers (EV) NEC ARTICLE 625.41)	5	EA	3.1	kW		17.2	15.50	25%	4.31	3.88	Level 2 Type Chargers, NO LEVEL 3 Chargers	33,945.00
GEN-012	Electrical Vehicle Chargers (EV) NEC ARTICLE 625.41) **FUTURE**	5	EA	3.1	kW		17.2	15.50	0%	0.00	0.00	Level 2 Type Chargers, NO LEVEL 3 Chargers	-
													-
GEN-013	Heat Tracing	500	LF	8	Watt/LF		4.4	4.00	50%	2.22	2.00		17,520.00
	GARAGE GENERAL SUB-TOTAL ELECTRICAL LOAD					*0.00*	*146.03*	*121.43*		*25.88*	*22.29*		195,266.36
	HVAC												
HVAC-001	IDF AC (2 Rooms on Level 4)	2	Each	2.81	kW		6.2	5.62	0%	0.00	0.00	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	
HVAC-002	IDF Heat (2 Rooms on Level 4)	2	Each	6.55	kW		14.6	13.10	25%	3.64	3.28	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	28,689.00
HVAC-003	Elec Rooms Exhaust Fan (2 Rooms on Level 4)	2	Each	0.5	kW		1.1	1.00	0%	0.00	0.00	CSP-A1050	
HVAC-004	Elec Rooms Heat (2 Rooms on Level 4)	2	Each	3	kW		6.7	6.00	25%	1.67	1.50	QMARK CWH3404 Electric Unit Heater	13,140.00
	GARAGE HVAC SUB-TOTAL ELECTRICAL LOAD					*0.00*	*28.58*	*25.72*		*5.31*	*4.78*		41,829.00
	Pumps, Water Heater, Air Compressor												
	GARAGE HVAC SUB-TOTAL ELECTRICAL LOAD					*0.00*	*0.00*	*0.00*		*0.00*	*0.00*		
	GARAGE MISC. ELECTRICAL												
	GARAGE MISC. ELECTRICAL SUB-TOTAL ELECTRICAL LOAD					***0.00***	***0.00***	***0.00***		***0.00***	***0.00***		
	Substation Total Load: Garage Load						394.6	345.2		220.1	197.1		
												ANNUAL kW-Hrs/Year	1,726,736.64

Massport
LAPP - Logan 5000 Economy Parking Structure-DESIGN CASE

Revision 1
Date 3/26/2019

Electrical Load Calculations

Normal Power Load

No.	Load Description	No. of Units	Unit of Measure	Unit Load Watt or kW		Full Load Amperes (A)	Connected Load, KVA	Connected Load, KW	Diversity Factor	Diversity Load, KVA	Diviersity Load, KW	Comments/Remarks/Assumptions	Annual Consumption, KWh
						CONNECTED LOAD			DIVERSIFIED LOAD				
	LIGHTING												
LTG-001	Lighting (Garage)	580,000	Area-SF	0.089	Watt/SF		57.4	51.62	75%	43.02	38.72	Current sketches show a 0.089 W/sq-ft. 75% DF based on integral occ sesnsors on each fixture.	339,143.40
LTG-002	Lighting (Garage Existing)	573,125	Area-SF	0.152	Watt/SF		96.7	87.00	100%	96.67	87.00	Existing Calc	762,123.29
LTG-003	Lighting (Mechanical / Electrical Spaces)	1,000	Area-SF	0.8	Watt/SF		0.9	0.80	50%	0.44	0.40		3,504.00
LTG-004	Lighting (Offices, Conference Rooms, Toilets, Corridors, etc.)	-	Area-SF	0.8	Watt/SF				80%	0.00	0.00	No Planned Office Space	
LTG-005	Lighting (Roadway)	-	LS	0	KVA				65%	0.00	0.00	No Planned Roadway Lighting served from Garage	
LTG-006	Lighting (Linear Façade)	-	LF	6	Watt/LF		0.0	0.00	65%	0.00	0.00	No Planned Façade Lighting	
LTG-007	Lighting (Elevator Lobbies)	-	Area-SF	1.6	Watt/SF		0.0	0.00	100%	0.00	0.00	No Planned Elevator Lobbies	
	GARAGE LIGHTING SUB-TOTAL ELECTRICAL LOAD						*154.91*	*139.42*		*140.13*	*126.12*		1,104,770.69
	GENERAL POWER												
GEN-001	Receptacles (Garage) 1st 10KVA	322	EA	0.18	kW		11.1	10.00	10%	1.11	1.00	1st 10KVA at 100%, assumed 2 per 60' x 60' bay.	8,760.00
GEN-002	Receptacles (Garage) Remaining						53.3	48.00	10%	5.33	4.80	Remaining at 50%	42,048.00
GEN-003	Receptacles (Ancillary Rooms) 1st 10KVA	50	EA	0.18	kW		10.0	9.00	10%	1.00	0.90	1st 10KVA at 100%, Estimated at 50 total.	7,884.00
GEN-004	Receptacles (Ancillary Rooms) Remaining						0.0	0.00	10%	0.00	0.00	Remaining at 50%	-
													-
GEN-005	Receptacles (Elevator Lobbies) 1st 10KVA	-	EA	0.18	kW		11.1	10.00	10%	1.11	1.00	1st 10KVA at 100%, Estimated at 70 total.	8,760.00
GEN-006	Receptacles (Elevator Lobbies) Remaining						0.0	-10.00	10%	0.00	-1.00	Remaining at 50%	(8,760.00)
													-
	IDF Rooms												-
GEN-007	IDF-01	1	EA	60	A		21.6	19.43	50%	10.80	9.72		85,109.36
													-
GEN-011	Electrical Vehicle Chargers (EV) NEC ARTICLE 625.41)	5	EA	3.1	kW		17.2	15.50	25%	4.31	3.88	Level 2 Type Chargers, NO LEVEL 3 Chargers	33,945.00
GEN-012	Electrical Vehicle Chargers (EV) NEC ARTICLE 625.41) **FUTURE**	5	EA	3.1	kW		17.2	15.50	0%	0.00	0.00	Level 2 Type Chargers, NO LEVEL 3 Chargers	-
													-
GEN-013	Heat Tracing	500	LF	8	Watt/LF		4.4	4.00	50%	2.22	2.00		17,520.00
	GARAGE GENERAL SUB-TOTAL ELECTRICAL LOAD					*0.00*	*146.03*	*121.43*		*25.88*	*22.29*		195,266.36
	HVAC												
HVAC-001	IDF AC (2 Rooms on Level 4)	2	Each	2.81	kW		6.2	5.62	0%	0.00	0.00	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	
HVAC-002	IDF Heat (2 Rooms on Level 4)	2	Each	6.55	kW		14.6	13.10	25%	3.64	3.28	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	28,689.00
HVAC-003	Elec Rooms Exhaust Fan (2 Rooms on Level 4)	2	Each	0.5	kW		1.1	1.00	0%	0.00	0.00	CSP-A1050	
HVAC-004	Elec Rooms Heat (2 Rooms on Level 4)	2	Each	3	kW		6.7	6.00	25%	1.67	1.50	QMARK CWH3404 Electric Unit Heater	13,140.00
	GARAGE HVAC SUB-TOTAL ELECTRICAL LOAD					*0.00*	*28.58*	*25.72*		*5.31*	*4.78*		41,829.00
	Pumps, Water Heater, Air Compressor												
	GARAGE HVAC SUB-TOTAL ELECTRICAL LOAD					*0.00*	*0.00*	*0.00*		*0.00*	*0.00*		
	GARAGE MISC. ELECTRICAL												
	GARAGE MISC. ELECTRICAL SUB-TOTAL ELECTRICAL LOAD					*0.00*	*0.00*	*0.00*		*0.00*	*0.00*		
	Substation Total Load: Garage Load						329.5	286.6		171.3	153.2		

ANNUAL kW-Hrs/Year	1,341,866.04

Massport
LAPP - Logan 5000 Garage Terminal E-BASE CASE

Revision 1
Date 3/26/2019

Electrical Load Calculations

739,054 1.871%

Normal Power Load 14,094 753,148

No.	Load Description	No. of Units	Unit of Measure	Unit Load Watt or kW		CONNECTED LOAD Full Load Amperes (A)	CONNECTED LOAD Connected Load, KVA	CONNECTED LOAD Connected Load, KW	DIVERSIFIED LOAD Diversity Factor	DIVERSIFIED LOAD Diversity Load, KVA	DIVERSIFIED LOAD Diviersity Load, KW	Comments/Remarks/Assumptions	Annual Consumption, KWh
	LIGHTING												
LTG-001	Lighting (Garage Interior) Levels 1-3 East/West	449,193	Area-SF	0.19	Watt/SF		94.8	85.35	100%	94.83	85.35	No Occ Sensors. On 24/7/365	747,636.83
LTG-002	Lighting (Garage Interior) Levels 4 East	70,065	Area-SF	0.19	Watt/SF		14.8	13.31	100%	14.79	13.31	No Occ Sensors. On 24/7/365	116,616.19
LTG-003	Lighting (Garage Interior) Levels 5 East	70,065	Area-SF	0.19	Watt/SF		14.8	13.31	100%	14.79	13.31	No Occ Sensors. On 24/7/365	116,616.19
LTG-004	Lighting (Garage Exterior Roof) Level 4 West	79,666	Area-SF	0.13	Watt/SF		11.5	10.36	60%	6.90	6.21	On at Night (Dusk-Dawn)	54,434.18
LTG-005	Lighting (Garage Exterior Roof) Level 6 East	70,065	Area-SF	0.13	Watt/SF		10.1	9.11	60%	6.07	5.47	On at Night (Dusk-Dawn)	47,874.01
LTG-006	Lighting (Mechanical / Electrical Spaces)	6,738	Area-SF	0.95	Watt/SF		7.1	6.40	50%	3.56	3.20	1.5% of overall garage space (estimated)	28,036.38
LTG-007	Lighting (Offices, Conference Rooms, Toilets, Corridors, etc.)	-	Area-SF	0.8	Watt/SF				80%	0.00	0.00	No Planned Office Space	-
LTG-008	Lighting (Roadway)	-	LS	0	KVA				65%	0.00	0.00	No Planned Roadway Lighting served from Garage	-
LTG-009	Lighting (Linear Façade)	93,439	Area-SF	0.15	Watt/SF		15.6	14.02	50%	7.79	7.01		61,389.42
LTG-010	Lighting (Elevator Lobbies)	7,356	Area-SF	0.64	Watt/SF		5.2	4.71	100%	5.23	4.71		41,240.68
	GARAGE LIGHTING SUB-TOTAL ELECTRICAL LOAD						*173.96*	*156.56*		*153.96*	*138.57*		1,213,843.88
	GENERAL POWER												
GEN-001	Receptacles (Garage) 1st 10KVA	250	EA	0.18	kW		11.1	10.00	10%	1.11	1.00	1st 10KVA at 100%, assumed 2 per 60' x 60' bay.	8,760.00
GEN-002	Receptacles (Garage) Remaining						38.8	34.92	10%	3.88	3.49	Remaining at 50%	30,589.31
													-
GEN-003	Receptacles (Ancillary Rooms) 1st 10KVA	50	EA	0.18	kW		10.0	9.00	10%	1.00	0.90	1st 10KVA at 100%, Estimated at 50 total.	7,884.00
GEN-004	Receptacles (Ancillary Rooms) Remaining						0.0	0.00	10%	0.00	0.00	Remaining at 50%	-
													-
GEN-005	Receptacles (Elevator Lobbies) 1st 10KVA	70	EA	0.18	kW		11.1	10.00	10%	1.11	1.00	1st 10KVA at 100%, Estimated at 70 total.	8,760.00
GEN-006	Receptacles (Elevator Lobbies) Remaining						0.0	2.60	10%	0.00	0.26	Remaining at 50%	2,277.60
	IDF Rooms												
GEN-007	IDF-01	1	EA	60	A		21.6	19.43	50%	10.80	9.72		85,109.36
GEN-008	IDF-02	1	EA	60	A		21.6	19.43	50%	10.80	9.72		85,109.36
GEN-009	IDF-03	1	EA	60	A		21.6	19.43	50%	10.80	9.72		85,109.36
GEN-010	MDF	1	EA	100	A		36.0	32.39	50%	17.99	16.19		141,848.93
GEN-011	Electrical Vehicle Chargers (EV) NEC ARTICLE 625.41)	15	EA	3.1	kW		51.7	46.50	25%	12.92	11.63	Level 2 Type Chargers, NO LEVEL 3 Chargers	101,835.00
GEN-012	Electrical Vehicle Chargers (EV) NEC ARTICLE 625.41) **FUTURE**	15	EA	3.1	kW		51.7	46.50	0%	0.00	0.00	Level 2 Type Chargers, NO LEVEL 3 Chargers	-
GEN-013	Heat Tracing	3,000	LF	8	Watt/LF		26.7	24.00	50%	13.33	12.00		105,120.00
	GARAGE GENERAL SUB-TOTAL ELECTRICAL LOAD					*0.00*	*301.78*	*274.20*		*83.73*	*75.62*		662,402.91
	HVAC												
HVAC-001	IDF AC (East Level 2, West Level 2, East Level 5)	3	Each	2.81	kW		9.4	8.43	0%	0.00	0.00	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	-
HVAC-002	IDF Heat (East Level 2, West Level 2, East Level 5)	3	Each	6.55	kW		21.8	19.65	25%	5.46	4.91	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	43,033.50
HVAC-003	MDF AC	2	Each	2.48	kW		5.5	4.96	0%	0.00	0.00	Mitsubishi Heat Pump PCA-A30KA4 & PUZ-HA30NHA2	-
HVAC-004	MDF Heat	2	Each	5.83	kW		13.0	11.66	25%	3.24	2.92	Mitsubishi Heat Pump PCA-A30KA4 & PUZ-HA30NHA2	25,535.40
HVAC-005	Main Electrical Room Exhaust Fans	2	Each	3	HP		4.97	4.48	0%	0.00	0.00	GreenHeck SBCE-3H36-30	-
HVAC-006	Main Electrical Room Heat	2	Each	10	kW		22.2	20.00	25%	5.56	5.00	QMARK MUSH-10-4 Electric Unit Heater	43,800.00
HVAC-007	Elec Rooms Exhaust Fan (East Level 2, West Level 2, East Level 5)	3	Each	0.5	kW		1.7	1.50	0%	0.00	0.00	CSP-A1050	-
HVAC-008	Elec Rooms Heat (East Level 2, West Level 2, East Level 5)	3	Each	3	kW		10.0	9.00	25%	2.50	2.25	QMARK CWH3404 Electric Unit Heater	19,710.00
HVAC-009	Elevator Control Room AC	1	Each	2.81	kW		3.1	2.81	0%	0.00	0.00	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	-
HVAC-010	Elevator Control Room Heat	1	Each	6.55	kW		7.3	6.55	25%	1.82	1.64	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	14,344.50
HVAC-011	Water Room (Exhaust Fan)	1	Each	0.8	KVA		0.8	0.72	0%	0.00	0.00		-
HVAC-012	Water Room (Heat)	1	Each	3	kW		3.3	3.00	25%	0.83	0.75		6,570.00
	GARAGE HVAC SUB-TOTAL ELECTRICAL LOAD					*0.00*	*103.06*	*92.76*		*19.41*	*17.47*		152,993.40

	Pumps, Water Heater, Air Compressor											
MECH-001	Elevator Sump Pumps	4	Each	2	HP		6.6	5.97	10%	0.66	0.60	
MECH-002	Water Heater (?)	1	Each	2	kW		2.0	2.00	25%	0.50	0.50	
	GARAGE HVAC SUB-TOTAL ELECTRICAL LOAD					*0.00*	*8.63*	*7.97*		*1.16*	*1.10*	
	GARAGE MISC. ELECTRICAL											
MISC-001	Booths (Includes HVAC, Gate Arm, Receptacles)	7	Each	20	kW		155.6	140.00	15%	23.33	21.00	
MISC-002	Elevators	4	Each	40	HP		132.6	119.36	25%	33.16	29.84	
MISC-003	Escalators	-	Each	10	HP		0.0	0.00	0%	0.00	0.00	
	GARAGE MISC. ELECTRICAL SUB-TOTAL ELECTRICAL LOAD					*0.00*	*288.18*	*259.36*		*56.49*	*50.84*	
	Substation Total Load: Garage Load						875.6	790.8		314.8	283.6	

ANNUAL kW-Hrs/Year	2,029,240.19

Massport

LAPP - Logan 5000 Garage Terminal E-DESIGN CASE

Revision 2
Date 3/26/2019

Electrical Load Calculations

Normal Power Load

							CONNECTED LOAD			DIVERSIFIED LOAD			
No.	**Load Description**	**No. of Units**	**Unit of Measure**	**Unit Load Watt or kW**		**Full Load Amperes (A)**	**Connected Load, KVA**	**Connected Load, KW**	**Diversity Factor**	**Diversity Load, KVA**	**Diviersity Load, KW**	**Comments/Remarks/Assumptions**	**Annual Consumption, KWh**
	LIGHTING												
LTG-001	Lighting (Garage Interior) Levels 1-3 East/West	449,193	Area-SF	0.089	Watt/SF		44.4	39.98	75%	33.32	29.98	Current sketches show a 0.089 W/sq-ft. 75% DF based on integral occ sesnsors on each fixture.	262,656.62
LTG-002	Lighting (Garage Interior) Levels 4 East	70,065	Area-SF	0.089	Watt/SF		6.9	6.24	75%	5.20	4.68	Current sketches show a 0.089 W/sq-ft. 75% DF based on integral occ sesnsors on each fixture.	40,969.11
LTG-003	Lighting (Garage Interior) Levels 5 East	70,065	Area-SF	0.089	Watt/SF		6.9	6.24	75%	5.20	4.68	Current sketches show a 0.089 W/sq-ft. 75% DF based on integral occ sesnsors on each fixture.	40,969.11
LTG-004	Lighting (Garage Exterior Roof) Level 4 West	79,666	Area-SF	0.089	Watt/SF		7.9	7.09	60%	4.73	4.25	On at Night (Dusk-Dawn)	37,266.48
LTG-005	Lighting (Garage Exterior Roof) Level 6 East	70,065	Area-SF	0.089	Watt/SF		6.9	6.24	60%	4.16	3.74	On at Night (Dusk-Dawn)	32,775.29
LTG-006	Lighting (Mechanical / Electrical Spaces)	6,738	Area-SF	0.5	Watt/SF		3.7	3.37	50%	1.87	1.68	1.5% of overall garage space (estimated)	14,755.99
LTG-007	Lighting (Offices, Conference Rooms, Toilets, Corridors, etc.)	-	Area-SF	0.8	Watt/SF				80%	0.00	0.00	No Planned Office Space	-
LTG-008	Lighting (Roadway)	-	LS	0	KVA				65%	0.00	0.00	No Planned Roadway Lighting served from Garage	-
LTG-009	Lighting (Linear Façade)	93,439	Area-SF	0.15	Watt/SF		15.6	14.02	50%	7.79	7.01		61,389.42
LTG-010	Lighting (Elevator Lobbies)	7,356	Area-SF	0.5	Watt/SF		4.1	3.68	100%	4.09	3.68		32,219.28
	GARAGE LIGHTING SUB-TOTAL ELECTRICAL LOAD						*96.49*	*86.84*		*66.34*	*59.70*		523,001.30
	GENERAL POWER												
GEN-001	Receptacles (Garage) 1st 10KVA	250	EA	0.18	kW		11.1	10.00	10%	1.11	1.00	1st 10KVA at 100%, assumed 2 per 60' x 60' bay.	8,760.00
GEN-002	Receptacles (Garage) Remaining						38.8	34.92	10%	3.88	3.49	Remaining at 50%	30,589.31
GEN-003	Receptacles (Ancillary Rooms) 1st 10KVA	50	EA	0.18	kW		10.0	9.00	10%	1.00	0.90	1st 10KVA at 100%, Estimated at 50 total.	7,884.00
GEN-004	Receptacles (Ancillary Rooms) Remaining						0.0	0.00	10%	0.00	0.00	Remaining at 50%	-
GEN-005	Receptacles (Elevator Lobbies) 1st 10KVA	70	EA	0.18	kW		11.1	10.00	10%	1.11	1.00	1st 10KVA at 100%, Estimated at 70 total.	8,760.00
GEN-006	Receptacles (Elevator Lobbies) Remaining						0.0	2.60	10%	0.00	0.26	Remaining at 50%	2,277.60
	IDF Rooms												
GEN-007	IDF-01	1	EA	60	A		21.6	19.43	50%	10.80	9.72		85,109.36
GEN-008	IDF-02	1	EA	60	A		21.6	19.43	50%	10.80	9.72		85,109.36
GEN-009	IDF-03	1	EA	60	A		21.6	19.43	50%	10.80	9.72		85,109.36
GEN-010	MDF	1	EA	100	A		36.0	32.39	50%	17.99	16.19		141,848.93
GEN-011	Electrical Vehicle Chargers (EV) NEC ARTICLE 625.41)	15	EA	3.1	kW		51.7	46.50	25%	12.92	11.63	Level 2 Type Chargers, NO LEVEL 3 Chargers	101,835.00
GEN-012	Electrical Vehicle Chargers (EV) NEC ARTICLE 625.41) **FUTURE**	15	EA	3.1	kW		51.7	46.50	0%	0.00	0.00	Level 2 Type Chargers, NO LEVEL 3 Chargers	-
GEN-013	Heat Tracing	3,000	LF	8	Watt/LF		26.7	24.00	50%	13.33	12.00		105,120.00
	GARAGE GENERAL SUB-TOTAL ELECTRICAL LOAD					*0.00*	*301.78*	*274.20*		*83.73*	*75.62*		662,402.91
	HVAC												
HVAC-001	IDF AC (East Level 2, West Level 2, East Level 5)	3	Each	2.81	kW		9.4	8.43	0%	0.00	0.00	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	-
HVAC-002	IDF Heat (East Level 2, West Level 2, East Level 5)	3	Each	6.55	kW		21.8	19.65	25%	5.46	4.91	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	43,033.50
HVAC-003	MDF AC	2	Each	2.48	kW		5.5	4.96	0%	0.00	0.00	Mitsubishi Heat Pump PCA-A30KA4 & PUZ-HA30NHA2	-
HVAC-004	MDF Heat	2	Each	5.83	kW		13.0	11.66	25%	3.24	2.92	Mitsubishi Heat Pump PCA-A30KA4 & PUZ-HA30NHA2	25,535.40
HVAC-005	Main Electrical Room Exhaust Fans	2	Each	3	HP		4.97	4.48	0%	0.00	0.00	GreenHeck SBCE-3H36-30	-
HVAC-006	Main Electrical Room Heat	2	Each	10	kW		22.2	20.00	25%	5.56	5.00	QMARK MUSH-10-4 Electric Unit Heater	43,800.00
HVAC-007	Elec Rooms Exhaust Fan (East Level 2, West Level 2, East Level 5)	3	Each	0.5	kW		1.7	1.50	0%	0.00	0.00	CSP-A1050	-
HVAC-008	Elec Rooms Heat (East Level 2, West Level 2, East Level 5)	3	Each	3	kW		10.0	9.00	25%	2.50	2.25	QMARK CWH3404 Electric Unit Heater	19,710.00
HVAC-009	Elevator Control Room AC	1	Each	2.81	kW		3.1	2.81	0%	0.00	0.00	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	-
HVAC-010	Elevator Control Room Heat	1	Each	6.55	kW		7.3	6.55	25%	1.82	1.64	Mitsubishi Heat Pump PCA-A36KA4 & PUZ-HA36NHA2 (Each Room)	14,344.50
HVAC-011	Water Room (Exhaust Fan)	1	Each	0.8	KVA		0.8	0.72	0%	0.00	0.00		-
HVAC-012	Water Room (Heat)	1	Each	3	kW		3.3	3.00	25%	0.83	0.75		6,570.00
	GARAGE HVAC SUB-TOTAL ELECTRICAL LOAD					*0.00*	*103.06*	*92.76*		*19.41*	*17.47*		152,993.40

	Pumps, Water Heater, Air Compressor													
MECH-001	Elevator Sump Pumps	4	Each	2	HP		6.6	5.97		10%	0.66	0.60		
MECH-002	Water Heater (?)	1	Each	2	kW		2.0	2.00		25%	0.50	0.50		
	GARAGE HVAC SUB-TOTAL ELECTRICAL LOAD					*0.00*	*8.63*	*7.97*			*1.16*	*1.10*		
	GARAGE MISC. ELECTRICAL													
MISC-001	Booths (Includes HVAC, Gate Arm, Receptacles)	7	Each	20	kW		155.6	140.00		15%	23.33	21.00		
MISC-002	Elevators	4	Each	40	HP		132.6	119.36		25%	33.16	29.84		
MISC-003	Escalators	-	Each	10	HP		0.0	0.00		0%	0.00	0.00		
	GARAGE MISC. ELECTRICAL SUB-TOTAL ELECTRICAL LOAD					*0.00*	*288.18*	*259.36*			*56.49*	*50.84*		
	Substation Total Load: Garage Load						798.1	721.1			227.1	204.7		
													ANNUAL kW-Hrs/Year	1,338,397.60