ENVIRONMENTAL AND HEALTH IMPACTS OF SHIFTING DRAYAGE TRUCK OPERATIONS TO OFF-PEAK HOURS
An Analysis of the PierPASS Program in Southern California

Ankoor Bhagat, Ph.D.
Civil and Environmental Engineering
Institute of Transportation Studies
University of California
Irvine, CA 92697-3600
Phone: 949-824-5989; Email: abhagat@uci.edu

Jean-Daniel Saphores, Ph.D.
Corresponding Author, Professor
Civil and Environmental Engineering
Planning, Policy & Design, and Economics
Institute of Transportation Studies
University of California
Irvine, CA 92697-3600
Phone: 949-824-7334; Email: saphores@uci.edu

R. Jayakrishnan, Ph.D.
Professor
Civil and Environmental Engineering
Institute of Transportation Studies
University of California
Irvine, CA 92697-3600
Phone: 949-824-8385; Email: rjayakri@uci.edu

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ABSTRACT
This paper analyses some environmental and health impacts from the PierPASS program, which shifted drayage trucks operations from daytime/peak hours to evening/night hours to reduce congestion and air pollution at the San Pedro Bay Ports (i.e. the Ports of Los Angeles and Long Beach in Southern California). We focus on emissions of nitrogen dioxide (NO₂) and particulate matter (PM₂.₅), and some related health impacts, using a framework that integrates microscopic traffic simulation with emission estimation, air dispersion, and a health impact assessment. We find that PierPASS had little impact on traffic congestion and slightly decreased overall emissions of NO₂ and PM₂.₅. However, PierPASS substantially changed their day-night distributions: at night, total port truck emissions increased by 19.4% for NO₂ and by 19.5% for PM₂.₅, while daytime emissions decreased respectively by 5.0% and 4.9%. As a result, PierPASS increased air pollutant concentrations during both daytime and nighttime because of atmospheric boundary layer effects. Finally, health impact analyses using EPA’s BenMAP model show that the implementation of PierPASS increased annual health costs in our study area (which does not include the ports themselves) by over $430 million.

Keywords: PierPASS; urban freight; Microsimulation; MOVES; CALPUFF; BenMAP; Environmental Impacts; Health Impacts.
1. INTRODUCTION

Various policies have been proposed to deal with the congestion and the air pollution generated by freight operations, including adopting cleaner vehicle technologies (such as the Clean Trucks Program in Southern California), mandating cleaner fuels, shifting container transport from trucks to trains for long distance travel, or shifting freight deliveries from peak to off-peak hours. The purpose of this paper is to examine some environmental and health impacts of the PierPASS program in Southern California.

The idea of shifting freight deliveries to off-peak hours to reduce urban congestion was implemented recently in California to address congestion and air pollution from drayage trucks serving the San Pedro Bay Ports (Ports of Los Angeles and Long Beach; SPBP), which is the largest port complex in the United States. Although ships are typically serviced continuously in the United States, drayage operations are limited by terminal operating practices, which typically occur on weekdays during normal business hours. After a first attempt to reduce truck queues at terminal gates by promoting off-peak deliveries via gate appointments during off-peak operating hours (Assembly Bill 2650, passed in 2000), the SPBP and terminal operators in July 2005 implemented the voluntary PierPASS program. PierPASS extends gate operations and imposes a fee on container moves during regular hours from Monday to Thursday; proceeds from this fee are allocated to terminal operators to offset additional costs associated with extended gate operations [1].

Using TransCAD and Caltrans count data, Giuliano and O’Brien [1] found that PierPASS has been successful at containing peak period congestion and at reducing midday congestion in spite of growth in container volumes. However, Sathaye et al. [2] showed that shifting freight transportation to nighttime disproportionately increases local air pollution because the atmospheric boundary layer is more stable at night than during the day. We note that neither study used microsimulation, so the potential benefits of shifting freight deliveries to off-peak hours are still controversial.

In this context, this paper analyzes changes in emissions of nitrogen dioxide (NO₂) and particulate matter (PM) and some of their associated health impacts resulting from the implementation of PierPASS because PM and NOₓ are the main pollutants emitted by heavy-duty port diesel trucks, and almost all NOₓ at concentrations below 80 µg/m³ transforms to NO₂ [3]. Our study area stretches from the gates of the SPBP to downtown Los Angeles; it includes portions of several major freeways, and a number of major local arterials where drayage trucks drive past schools, parks, and residences. Our study area does not, however, include the Ports themselves because of a lack of information about truck movements and truck queues at the terminals. Our methodology combines microscopic traffic simulation (TransModeler) with EPA’s MOVES model to obtain vehicular emissions of PM and NO₂, which are then dispersed using CalPUFF, before some of their health impacts are estimated using EPA’s BenMap model. After calibrating our model using a dynamic origin-destination demand estimation algorithm for a representative day in 2005, we ran 24-hour simulations for two scenarios: (1) a baseline, pre-PierPASS scenario; and (2) a post-PierPASS scenario obtained by shifting drayage truck traffic from peak to off-peak hours based on observed information.

The next section provides background information. In Section 3, we summarize our methodology and outline our data sources. In Section 4 we present our results before summarizing our findings and suggesting ideas for future research in Section 5.
2. BACKGROUND

The idea of shifting freight deliveries to off-peak hours has a long history: for example, around 45 B.C., the Roman Emperor Julius Cesar allowed commercial deliveries only during evening hours to reduce urban congestion [4]. In recent years proposals to shift logistics operations to nighttime have grabbed again the attention of policymakers. Indeed, a number of studies suggest that off-peak policies and nighttime delivery operations can reduce traffic congestion and emissions. For example, a case study in the United Kingdom shows that delivering goods during nighttime and on Sundays reduces air pollution, improves daytime traffic flows, and enhances the effectiveness of deliveries [5].

Around the world off-peak policies have being implemented to reduce traffic congestion and emissions from vehicles. Geroliminis and Daganzo [6] review examples of green logistics schemes implemented in various cities including Paris, Barcelona and Rome. In Barcelona, some boulevards have been dedicated to off-peak deliveries [7].

In California (especially around the SPBP), off-peak delivery policies were promoted by the passage of California Assembly Bill (AB) 2650 in year 2000, which encouraged port terminals to adopt gate appointments and off-peak operating hours to reduce idling truck queues at gates. Moreover, penalties could be applied to trucks idling in queues for more than 30 minutes [8]. However, Giuliano and O'Brien [8] found no evidence that AB 2650 reduced truck emissions.

The PierPASS off-peak program was launched on July 23, 2005 to reduce traffic congestion and improve air quality around the SPBP complex. It created two prominent shifts in drayage truck traffic: daytime traffic was reduced and truck trips between 6:00 PM and 1:00 AM increased substantially [1]. Before PierPASS up to 21% of port traffic moved during off-peak hours, but since the inception of PierPASS, this percentage has soared to 45% [1].

However, some recent studies [2, 9, 10] have highlighted some environment and health drawbacks of off-peak logistic operations. These studies found that shifting freight transportation to nighttime may disproportionally increase concentrations of local air pollutant because the atmospheric boundary layer is more stable at night than during the day.

Panis and Beckx [9] relied on Gaussian plume dispersion modeling to study the impact on air pollution of shifting the timing of truck transportation activity to nighttime in the port of Antwerp (Belgium); their results indicate that emission concentrations are higher at night than during the day. Hu et al. [10] studied air pollutant concentration downstream of a segment of the I-10 freeway in Santa Monica during pre-sunrise hours. They report that even though traffic volumes on the freeway during pre-sunrise hours were lower than that during the day, downwind air pollutant concentrations were significantly higher. They attributed this phenomenon to atmospheric stability, low wind speeds, low temperatures and high humidity.

The work of Sathaye, Harley, and Madanat [2] is especially of interest here because they accounted for both different metrological conditions at night and for human intake while people are sleeping. They found that moving freight deliveries to off-peak hours would typically increase the 24-hour average exhaust concentrations of critical air pollutants as well as daily human intake. We note, however, that none of these studies relied on microscopic traffic simulation models to estimate emissions caused by the movement of freight trucks.

Another reason why restricting peak-period truck deliveries may have unintended consequences is that freight companies may circumvent peak-period restrictions by using smaller vehicles, thus increasing environmental impacts and traffic congestion, as illustrated by Los Angeles' attempt in 1991 to regulate large truck movements during peak hours [11].
recently, Quak and de Koster [12] study in the Netherlands found that time windows and vehicle restrictions (vehicle size and type) likely increased emissions of PM$_{10}$, NO$_x$, and CO$_2$.

Another environmental drawback of off-peak delivery is noise pollution from logistic operations at night [5]. In Barcelona for example, concerns about noise pollution during nighttime deliveries motivated the requirement that trucks be equipped with anti-noise systems [6]. However, this paper does not consider the impacts of noise related to off-peak deliveries.

3. DATA AND METHODOLOGY
To analyze the environmental impacts of shifting freight deliveries to off-peak hours, we combined TransModeler [13], a microscopic traffic simulation model, with EPA's MOVES emissions model [14]. We then relied on CALPUFF [15] to disperse emissions of PM and NO$_2$ before analyzing some of their health impacts using BenMAP [16].

3.1 Traffic Simulation
To capture the impact of traffic dynamics on air pollutant emissions, we selected the microscopic traffic simulator TransModeler 3.0 because it offers a number of advantages over other microscopic traffic simulators. First, it is versatile: it can simulate a wide range of road types and traffic conditions while accounting for traffic signals and ITS operations. Second, TransModeler works seamlessly with TransCAD and with Geographic Information System (GIS) data, both for inputting network information and for visualizing results. Third, it generates vehicle trajectory data that are easy to process to estimate emissions of various air pollutants. Finally, using TransModeler allowed us to extend the road network created during previous work [17].

3.1.1 Study Area and Network Data
Our study area, which extends north of the SPBP complex, is shown on Figure 1. Our starting network had 289.2 miles of freeways and 140.7 miles of arterials. We expanded it to 314.4 miles of freeway and 281 miles of arterials by adding parts of the I-405 as well as a number of arterial segments west of the I-110, north of the S-91, and east of the I-710.

Basic freeway and arterial layouts were extracted from a GIS layer provided by the California Department of Transportation (Caltrans) and basic freeway characteristics (e.g., number of lanes and speed limits) were obtained from Caltrans' freeway Performance Measurement System (PeMS). Additional geometric details were extracted from the TerraServer and from Google Earth maps.

Latitude and longitude data for each detector in our study area were collected from PeMS and entered in a GIS layer. Likewise, ramp metering controls - located using Google Earth's street view - were entered in a GIS layer. Since we could not obtain detailed information about freeway ramp metering, freeway ramp meters were set to release up to one vehicle per lane every two second (1800 vehicles per hour and per lane).

Arrival volumes and signal operations data were collected from traffic engineers working for Los Angeles County or for some of the cities in our study area (Carson, Lomita, Long Beach, Los Angeles, Lynwood, Rancho Palos Verdes, Rolling Hills Estates, and Torrance). Based on information provided by local traffic engineers, most traffic signals were modeled as actuated signals. For signalized intersections without traffic signal data, signal timing was assumed to be similar to the timing of nearby locations; moreover, signal timing parameters were manually adjusted to smooth traffic patterns during simulation. At intersections with no traffic signals, stop
or yield signs were installed based on information from Google Earth.

FIGURE 1 Study Area

Since performing iterative dynamic origin-destination demand estimations and calibrating network supply characteristics is very time consuming, we did not attempt to simulate traffic for multiple days. As in Lee et al. [17], March 9th, 2005 was selected as a typical weekday. We then simulated traffic for 24 hours, from 12:00 AM on March 9th, 2005, to 11:59 PM the same day, with the first 30 minutes serving to load traffic onto the network. A 24-hour simulation is much longer than microscopic simulations typically attempted in traffic operations studies.

3.1.2 O-D Estimation

Initial origin-destination (O-D) demands were obtained from a Southern California Association
of Governments traffic study [18, 19] that combined data from a SCAG Regional Transportation
Plan with stated drayage truck demand data from a survey conducted for the Port of Long Beach.
A sub-area analysis using TransCAD 5.0 was conducted to prepare the initial O-D demand
profiles by re-distributing O-D trips on the target area abstracted from the original SCAG
network.

These O-D demands were then adjusted to match traffic volumes observed from PeMS in
15 minute intervals based on 147 freeway mainline loop detectors, 86 freeway ramp detectors,
and 121 arterial detectors. Since PeMS traffic data were available neither on the I-710 south of
the I-405 nor on arterials, we relied on AADT data provided by Caltrans and local traffic
engineers. These AADT data were distributed in 15 minute increments first based on
TransCADâ€™s traffic distribution (by time period: morning peak from 6 AM to 9 AM, midday
from 9 PM to 3 PM, evening peak from 3 PM to 7 PM, and nighttime) and then based on local
simulation results while conserving total AADT.

Since no automated traffic counts were available for arterials, we combined bidirectional
traffic count data provided by the Los Angeles Department of Transportation, local traffic
engineers, and the Ports of Los Angeles and Long Beach. A portion of the data included counts
based on intersection movements: through, left turn, and right turn. For intersections without
such data, we assumed turning flow fractions similar to those of nearby locations.

To perform O-D estimation, we relied on the dynamic algorithm described by Choi et al.
[20] because this approach can generate more realistic congestion dynamics than static O-D
estimation, which is important for correctly estimating vehicular emissions. To our knowledge,
this project had among the largest truly dynamic O-D trip tables ever estimated in an urban area
simulation, with 96 time periods of 15 minutes each for 449 zones over 24 hours, and a total
demand of nearly 3.7 million vehicles. Each simulation run of this network over 24 hours
period, along with the associated OD flow update step following the processing of vehicle
trajectory files, took nearly a day. Thus completing the OD estimation in a reasonable number of
iterations was very important here.

To achieve convergence in a timely fashion, we developed a method that expands O-D
matrices from an embedded smaller network for which OD estimation was done earlier by Lee et
al. [17]. As our starting network was well-calibrated, we focused on developing OD patterns that
matched traffic in the areas added to the network after fixing the already-converged OD matrix
for the starting network; for details, see [21]. To our knowledge, such a method has not been
applied previously for dynamic O-D estimation.

3.1.3 Goodness of fit
As argued in [17], emission studies should focus on simulating representative levels of
congestion with transient queue formation, dissipation, and stop-and-go conditions over an entire
network. Following current accepted practice and FHWA recommendations [22], we relied on
the Geoffrey E. Havers (GEH) statistic to assess simulation results. The GEH statistic is a
modified Chi-squared statistic that considers differences between observed and simulated traffic
counts. For a given link, it is defined by:

\[
\text{GEH} = \frac{(M - S)^2}{0.5(M + S)},
\]

where M and S respectively represent observed and simulated traffic flows in vehicles per hour.
To further assess the match between simulated and observed freeway traffic, average speeds from simulation were compared with PeMS speeds at different times and for a range of links. For arterial roads, simulated average speeds were sampled to ensure their plausibility.

### 3.1.4 Scenarios

To study the environmental impacts of PierPASS, we considered two scenarios: (1) A pre-PierPASS scenario based on a 2004 temporal distribution of drayage truck trips, which reflects port drayage trucks operations before the implementation of PierPASS; and (2) A post-PierPASS scenario based on a 2007 temporal distribution of drayage truck trips [1] that reflects the shift in port drayage trucks that followed PierPASS.

We then applied each truck distribution to our 96 15-minute O-D matrices for each O-D related to port zones, while conserving the total number of Port trucks traveling on each O-D during the 24 hours of our simulation.

### 3.2 Emissions estimation

To take advantage of second-by-second vehicular speeds and accelerations provided by microscopic simulation, a microscopic emission model is necessary. This rules out macroscopic models such as EMFAC 2007, although it is required for regulatory work in California.

Three main microscopic emission models are currently available in the U.S.: VT-micro, from Virginia Tech [23]; CMEM, from the University of California, Riverside [24]; and MOVES [25]. Since VT-micro does not account for vehicle model year and CMEM cannot estimate PM emissions, we chose MOVES for this study.

MOVES offers three approaches for estimating vehicular emissions at the project level: 1) link average speed; 2) link driving schedule; and 3) vehicle operating mode (OpMode). The link average speed approach is attractive because of its simplicity but it fails to capture specific vehicle interactions in congested conditions. The link driving approach can compute emissions from second-by-second vehicle trajectory data but it is computationally very demanding for large networks. We therefore adopted the OpMode approach, which relies on modal binning based on vehicle specific power [25], and on vehicle speeds and accelerations from second-by-second trajectory data. The OpMode approach therefore allows estimating emissions from stop-and-go traffic conditions, but its computational requirements are much lower than those of the link driving schedule approach if, as suggested by Claggett [26], look-up tables are used, which was done in this study.

To calculate emissions, we had to reconcile vehicle categories used by TransModeler (five categories) and MOVES (16 categories). We relied on random drawings from a uniform distribution for each vehicle type to match the distribution of vehicles in the study area. Distributions of vehicle types, model years, and fuel type for Los Angeles County were extracted from EMFAC following the procedure recommended by [27]. We also collected data about the fleet distribution of drayage trucks from the Port of Long Beach [28].

### 3.3 Pollutant Dispersion

To study the dispersion of air pollutants generated via MOVES we used CALPUFF View 7.0.5, a commercial version of CALPUFF. It has three components: CALMET (a 3-D meteorological model), CALPUFF (a transport and dispersion model), and CALPOST (a post-processing module). We chose this software because it allows dispersion modeling under dynamic...
meteorological conditions, it accounts for complex terrain, and it calculates pollutant concentration for a wide range of time-scales.

### 3.3.1 Geophysical Data

Terrain, land use, and land cover data, which are needed to develop hourly wind and temperature fields on a three dimensional grid in CALMET were provided by U.S. DEM 1 Degree terrain data (coverage area of 1 by 1 degree blocks with approximately 90 by 90 meter resolution). For land use and land cover, which give information about major classes of land use, vegetation, water, natural surface, and cultural features, we used U.S. Geological Survey (U.S.G.S) Composite Theme Grid (CTG) U.S. Land use data with a 200 meter resolution.

### 3.3.2 Meteorological Data

For our meteorological data, we relied on 2005 CALMET-Ready MM5 data developed by Penn State/National Center for Atmospheric Research, which we purchased from Lakes Environmental. The MM5 dataset contains wind field data used for creating weather forecasts and climate projections.

### 3.3.3 Temporal Analysis

Pollutant dispersion analyses were performed for four seasons (quarters in fact) and for day-time versus night-time to account for variations in meteorological conditions and in exposure. We assumed that health impacts are driven by long term average exposure to pollutants. The two daily periods for aggregating hourly concentrations of pollutants are nighttime (from midnight to 7 am and from 7 pm to midnight, for a total of 12 hours) and daytime (from 7 am to 7 pm, for another 12 hours).

For each sampling receptor in our study area, we used CALPUFF to estimate hourly concentrations of NO$_2$ and PM$_{2.5}$ for each day of 2005 for both Pre and Post-PierPASS scenarios. We also calculated average nighttime and daytime seasonal pollutant concentration before and after PierPASS during various time periods at different sampling receptors.

### 3.4 Health Impacts

For appraising the health impacts associated with PierPASS, we relied on BenMAP-CE, which is a GIS-based program developed by the U.S. EPA [16] to calculate benefits and costs of air pollution regulations. BenMAP proceeds in three main steps: 1) it calculates air pollutant concentration changes resulting from a control scenario with respect to a baseline scenario; 2) it then combines this information with gridded population data to estimate the resulting health incidences using concentration-response functions (C-R functions); and 3) it calculates the monetary value of these health impacts by applying valuation functions.

#### 3.4.1 Health Effects

BenMAP uses concentration-response functions (C-R functions) derived from epidemiological studies to estimate health impacts. The relationship between the concentration of a pollutant, $x$, and the population response, $y$, is the concentration-response function, which can be written:

$$ \Delta y = f(\beta, \Delta x) \cdot y_0 \cdot Q, \tag{2} $$

where $\Delta y$ is the change in incidence rate between a baseline ($y_0$) and a control scenario ($y_c$); $\beta$ is a risk coefficient derived from epidemiological studies; $\Delta x$ is the corresponding change in air pollutant concentration; and $Q$ is the exposed population.
Conceptually, BenMAP calculates health impacts as the product of four terms [29]: 1) a change in air quality, which is the difference between a baseline and air pollution concentration after a change, induced for example by a new policy; 2) a health effect estimate, which is the percentage change in an adverse health effect resulting from a unit change in ambient air pollution; 3) the size of the exposed population; and 4) an estimate of the average number of health effects per person per unit time.

3.4.2 Economic Valuation of Health Effects
BenMAP offers several approaches for estimating the economic value of avoided health effects. For avoided mortality, it uses the value of a statistical life (VSL), which represents people\'s willingness to pay to reduce the risk of death. For other health effects, BenMAP relies on medical costs of related illnesses [29]. The value of a given health outcome is then calculated by multiplying the number of cases by the unit value of this outcome.

3.4.3 Population and Air Quality Data
For estimating changes in population exposure to PM and NO\(_x\), we relied on block-group level demographic data for Los Angeles County. We used the PopGrid program developed by Abt Associates [29] to construct specific population grids matching the age, race, ethnicity, and gender of the population of Los Angeles County based on 2010 data because they are readily available and the population of Los Angeles County did not change much between 2005 and 2010 (it only grew 0.15%, from 9,803,912 to 9,818,603).

3.4.4 PM\(_{2.5}\) and NO\(_x\) Health Impact Functions
To analyze the health impacts resulting from the implementation of PierPASS, we focused on NO\(_2\) and PM\(_{2.5}\). For PM\(_{2.5}\) exposure, we analyzed on mortality, chronic bronchitis, asthma exacerbation and hospital admissions due to cardiovascular and respiratory related symptoms. The risk coefficient or beta values for the corresponding health impact functions were derived from various epidemiological studies conducted in Los Angeles (see [21] for details). For NO\(_2\), we analyzed hospital admissions due to respiratory health endpoint asthma; unfortunately, we could not find relevant epidemiological data for other health impacts.

3.4.5 Valuation Functions
For valuing health endpoints, we used EPA\'s Standard Valuation Functions available in BenMAP-CE. For PM\(_{2.5}\) mortality, the value of a statistical life is approximately normally distributed between $1 million and $10 million. For the other PM\(_{2.5}\) exposure health endpoints and for NO\(_2\)-related asthma we used valuation functions based on cost of illness derived from medical costs and wages/earnings lost. Finally, for PM\(_{2.5}\) asthma exacerbation, we relied on a symptom day willingness-to-pay function based on Dickie and Ulery [30].

4. RESULTS
4.1 Microscopic Traffic Simulation Results
Both pre- and post-PierPASS scenarios involved 3.5 million light duty vehicles, 0.05 million light duty trucks, 0.039 million medium duty trucks, 0.048 million heavy duty trucks, and 0.056 million heavy duty port trucks, for a total of approximately 3.7 million vehicles. Of that total, 5.2% were trucks, 29% of which were port trucks. For comparing traffic results for both
scenarios we considered three performance measures: vehicle miles traveled (VMT), vehicle hours traveled (VHT), and average vehicle speed over the entire network. A summary of traffic simulation results is presented in Table 1.

As expected, VMT and VHT were approximately the same for both scenarios since port trucks account only for 1.5% of the 3.7 million of simulated vehicles. Changes in average speeds on freeways and arterials were also negligible following the implementation of PierPASS, except that heavy duty port trucks drove on average 11.3% faster. Overall, however, PierPASS had little impact on congestion in our study area.

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>No. of Vehicles</th>
<th>VMT (mi)</th>
<th>VHT (hr)</th>
<th>Q (mph) = VMT/VHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-PierPASS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Duty Vehicles</td>
<td>3,508,185</td>
<td>17,866,014</td>
<td>1,720,692</td>
<td>10.4</td>
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<tr>
<td>Light Duty Trucks</td>
<td>50,063</td>
<td>307,358</td>
<td>18,285</td>
<td>16.8</td>
</tr>
<tr>
<td>Medium Duty Trucks</td>
<td>39,074</td>
<td>206,658</td>
<td>19,840</td>
<td>10.4</td>
</tr>
<tr>
<td>Heavy Duty Trucks</td>
<td>47,843</td>
<td>282,448</td>
<td>26,135</td>
<td>10.8</td>
</tr>
<tr>
<td>Heavy Duty Port Trucks</td>
<td>56,116</td>
<td>594,882</td>
<td>30,092</td>
<td>19.8</td>
</tr>
<tr>
<td>Total</td>
<td>3,701,281</td>
<td>19,257,360</td>
<td>1,815,044</td>
<td>10.61 (13.6)*</td>
</tr>
<tr>
<td>Post-PierPASS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Duty Vehicles</td>
<td>3,508,861</td>
<td>17,866,434</td>
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<tr>
<td>Light Duty Trucks</td>
<td>50,088</td>
<td>308,030</td>
<td>18,313</td>
<td>16.8</td>
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<td>39,030</td>
<td>207,163</td>
<td>19,489</td>
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<td>282,608</td>
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<td>55,274</td>
<td>580,487</td>
<td>26,378</td>
<td>22.0</td>
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<tr>
<td>Total</td>
<td>3,701,063</td>
<td>19,244,723</td>
<td>1,796,842</td>
<td>10.71 (14.2)*</td>
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</table>

% change

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>% Change</th>
<th>% Change</th>
<th>% Change</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Duty Vehicles</td>
<td>0.019%</td>
<td>0.002%</td>
<td>-0.804%</td>
<td>0.813%</td>
</tr>
<tr>
<td>Light Duty Trucks</td>
<td>0.050%</td>
<td>0.219%</td>
<td>0.155%</td>
<td>0.064%</td>
</tr>
<tr>
<td>Medium Duty Trucks</td>
<td>-0.113%</td>
<td>0.244%</td>
<td>-1.769%</td>
<td>2.049%</td>
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<tr>
<td>Heavy Duty Trucks</td>
<td>-0.069%</td>
<td>0.057%</td>
<td>-1.268%</td>
<td>1.342%</td>
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<tr>
<td>Heavy Duty Port Trucks</td>
<td>-1.500%</td>
<td>-2.420%</td>
<td>-12.344%</td>
<td>11.322%</td>
</tr>
<tr>
<td>Total</td>
<td>-0.006%</td>
<td>-0.066%</td>
<td>-1.003%</td>
<td>0.947% (3.948%)*</td>
</tr>
</tbody>
</table>

Notes:
1. * indicates average speed in network considering all vehicle classes.
2. % Change (%Δ) = (Post-PierPASS - Pre-PierPASS)/Pre-PierPASS

4.2 Emission Estimation Results
A summary of emission results is presented in Table 2. Simulation results show that approximately 87.3% (=38.84/44.50) of NO2 emissions and 76.3% (=1356.3/1776.7) of PM2.5 emissions took place on freeways before PierPASS, versus 87.2% (=38.63/44.30) and 76.2% (=1344.4/1764.6) after PierPASS.

The main impact of PierPASS, however, was to shift emissions from daytime to nighttime: nighttime emissions of NO2 and PM2.5 increased by 19.41% and 19.52% respectively,
while corresponding daytime emissions decreased by 5.02% and 4.93% respectively. As expected, this shift is almost entirely due to heavy duty port trucks, which are responsible for almost half of total emissions of NO₂ and PM₂.₅ in our study area. PierPASS slightly decreased their contributions to emissions of these 2 pollutants during daytime - from slightly above 54.5% to approximately 52.4% - but it bumped up their contributions from just over 27% to just under 39% during nighttime.

Although overall emissions of NO₂ and PM₂.₅ decreased very slightly thanks to PierPASS (-0.47% for NO₂ and -0.68% for PM₂.₅), the concentrations of these pollutants increased in our study area, along with their corresponding health impacts, as explained below.

**Table 2 Summary of Emission Results**

<table>
<thead>
<tr>
<th></th>
<th>Pre-PierPASS</th>
<th>Post-PierPASS</th>
<th>Percentage change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NOx (tons)</td>
<td>PM₂.₅ (kg)</td>
<td>NOx (tons)</td>
</tr>
<tr>
<td><strong>Off-Peak (nighttime)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Duty Vehicles</td>
<td>4.528</td>
<td>168.465</td>
<td>4.526</td>
</tr>
<tr>
<td>Light Duty Trucks</td>
<td>0.113</td>
<td>2.675</td>
<td>0.114</td>
</tr>
<tr>
<td>Medium Duty Trucks</td>
<td>0.024</td>
<td>0.350</td>
<td>0.024</td>
</tr>
<tr>
<td>Heavy Duty Trucks</td>
<td>1.362</td>
<td>54.107</td>
<td>1.374</td>
</tr>
<tr>
<td>Heavy Duty Port Trucks</td>
<td>2.253</td>
<td>83.409</td>
<td>3.850</td>
</tr>
<tr>
<td>Arterials</td>
<td>0.928</td>
<td>70.019</td>
<td>1.103</td>
</tr>
<tr>
<td>Freeways</td>
<td>7.353</td>
<td>238.987</td>
<td>8.785</td>
</tr>
<tr>
<td><strong>All Vehicles</strong></td>
<td>8.281</td>
<td>309.006</td>
<td>9.888</td>
</tr>
<tr>
<td><strong>Peak (daytime)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Duty Vehicles</td>
<td>13.099</td>
<td>538.631</td>
<td>13.084</td>
</tr>
<tr>
<td>Light Duty Trucks</td>
<td>0.349</td>
<td>8.590</td>
<td>0.353</td>
</tr>
<tr>
<td>Medium Duty Trucks</td>
<td>0.072</td>
<td>1.030</td>
<td>0.071</td>
</tr>
<tr>
<td>Heavy Duty Trucks</td>
<td>2.836</td>
<td>118.203</td>
<td>2.821</td>
</tr>
<tr>
<td>Heavy Duty Port Trucks</td>
<td>19.868</td>
<td>801.231</td>
<td>18.077</td>
</tr>
<tr>
<td>Arterials</td>
<td>4.737</td>
<td>350.343</td>
<td>4.566</td>
</tr>
<tr>
<td>Freeways</td>
<td>31.487</td>
<td>1117.342</td>
<td>29.841</td>
</tr>
<tr>
<td><strong>All Vehicles</strong></td>
<td>36.224</td>
<td>1467.686</td>
<td>34.407</td>
</tr>
<tr>
<td><strong>All day</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Duty Vehicles</td>
<td>17.627</td>
<td>707.096</td>
<td>17.610</td>
</tr>
<tr>
<td>Light Duty Trucks</td>
<td>0.462</td>
<td>11.265</td>
<td>0.467</td>
</tr>
<tr>
<td>Medium Duty Trucks</td>
<td>0.097</td>
<td>1.381</td>
<td>0.095</td>
</tr>
<tr>
<td>Heavy Duty Trucks</td>
<td>4.198</td>
<td>172.310</td>
<td>4.195</td>
</tr>
<tr>
<td>Heavy Duty Port Trucks</td>
<td>22.121</td>
<td>884.640</td>
<td>21.928</td>
</tr>
<tr>
<td>Arterials</td>
<td>5.665</td>
<td>420.362</td>
<td>5.670</td>
</tr>
<tr>
<td>Freeways</td>
<td>38.840</td>
<td>1356.329</td>
<td>38.626</td>
</tr>
<tr>
<td><strong>All Vehicles</strong></td>
<td>44.505</td>
<td>1776.691</td>
<td>44.295</td>
</tr>
</tbody>
</table>

Notes:

1. Correcting for differences in miles traveled between the pre- and the post- PierPASS simulations makes only a small difference so the numbers above are uncorrected.
2. This table shows three significant digits not to imply precision but to be able to assess the magnitude of small changes.
3. Percentage changes are calculated as (Post-PierPASS - Pre-PierPASS)/Pre-PierPASS.
4.3 Pollutant Dispersion Results

For our dispersion analysis, we consider a square grid of 37 miles x 37 miles with 1369 equally spaced sampling receptors, so each receptor is at the center of a one square mile cell. The top part of Table 3 presents average seasonal concentrations for NO₂ and PM₂.₅ both before and after PierPASS; the bottom part of Table shows areas where seasonal averages increased by at least 1 µg/m³ for PM₂.₅ and by at least 30 µg/m³ for NO₂ after PierPASS compared to before PierPASS.

Table 3 Summary of Dispersion Analysis Results

<table>
<thead>
<tr>
<th>Season</th>
<th>Pre-PierPASS</th>
<th>Post-PierPASS</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO₂ (µg/m³)</td>
<td>NOₓ (µg/m³)</td>
<td>PM₂.₅ (µg/m³)</td>
</tr>
<tr>
<td>Night Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>111.10</td>
<td>118.09</td>
<td>6.3%</td>
</tr>
<tr>
<td>Spring</td>
<td>68.61</td>
<td>72.71</td>
<td>6.0%</td>
</tr>
<tr>
<td>Summer</td>
<td>76.38</td>
<td>80.80</td>
<td>5.8%</td>
</tr>
<tr>
<td>Fall</td>
<td>137.74</td>
<td>147.78</td>
<td>7.3%</td>
</tr>
<tr>
<td>Day Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>138.67</td>
<td>141.55</td>
<td>2.1%</td>
</tr>
<tr>
<td>Spring</td>
<td>90.99</td>
<td>92.75</td>
<td>1.9%</td>
</tr>
<tr>
<td>Summer</td>
<td>104.97</td>
<td>107.42</td>
<td>2.3%</td>
</tr>
<tr>
<td>Fall</td>
<td>170.02</td>
<td>175.30</td>
<td>3.1%</td>
</tr>
</tbody>
</table>

Areas where seasonal averages differ

<table>
<thead>
<tr>
<th>Season</th>
<th>NO₂ concentration difference &gt;= 30 µg/m³</th>
<th>PM₂.₅ concentration difference &gt;= 1 µg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>Area (Sq. Mile)</td>
<td>% Area</td>
</tr>
<tr>
<td></td>
<td>87</td>
<td>6.36%</td>
</tr>
<tr>
<td>Spring</td>
<td>29</td>
<td>2.12%</td>
</tr>
<tr>
<td>Summer</td>
<td>29</td>
<td>2.12%</td>
</tr>
<tr>
<td>Fall</td>
<td>115</td>
<td>8.40%</td>
</tr>
<tr>
<td>Winter</td>
<td>Area (Sq. Mile)</td>
<td>% Area</td>
</tr>
<tr>
<td></td>
<td>146</td>
<td>10.66%</td>
</tr>
<tr>
<td>Spring</td>
<td>60</td>
<td>4.38%</td>
</tr>
<tr>
<td>Summer</td>
<td>38</td>
<td>2.78%</td>
</tr>
<tr>
<td>Fall</td>
<td>186</td>
<td>13.59%</td>
</tr>
</tbody>
</table>

Starting with the top half of Table 3, we first note that the creation of PierPASS led to an increase in average seasonal concentrations for all seasons and for both NO₂ and PM₂.₅. This seemingly counter-intuitive result is due to an atmospheric boundary layer effect, i.e., to pollution left over from the previous night when the atmospheric boundary layer is stable. Since the pollution generated at night tends to linger, it adds to the pollution generated the next morning, resulting in a net increase in the concentration of pollution; everything else being the same, this increase is higher in the fall and lower in the summer.

The bottom half of Table 3 shows the extent of areas where NO₂ concentrations increased by more than 30 µg/m³ on average during a season, and where PM₂.₅ concentrations increased by...
more than 1 μg/m³ on average during a season (both thresholds were selected for convenience).

As expected, this increase is largest at night (compare to daytime) and during the fall for both NO₂ and PM₂.₅; conversely, it is smallest during the spring for both day and night for NO₂, and during the summer at night and the spring during the day for PM₂.₅. Most of the areas where pollutant concentration exceeds the thresholds are located in the vicinity of SPBP ports, south of the I-405 and between the I-110 and the I-710). We note that toward the edges of our study grid (away from emission sources), pollutant concentrations decreased slightly after PierPASS compared to before because pollutants were not transported there as readily as before PierPASS.

Table 4. Selected Health Impacts associated with PierPASS

<table>
<thead>
<tr>
<th>Health Endpoints</th>
<th>Measure</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Particulate Matter (PM₂.₅)</strong></td>
<td>Incidence</td>
<td>17.0</td>
<td>7.7</td>
<td>8.4</td>
<td>29.4</td>
<td>62.6</td>
</tr>
<tr>
<td>Mortality (30 - 99)</td>
<td>Valuation</td>
<td>$118.38</td>
<td>$53.85</td>
<td>$58.17</td>
<td>$204.59</td>
<td>$434.98</td>
</tr>
<tr>
<td><strong>Chronic Bronchitis (27 – 99)</strong></td>
<td>Incidence</td>
<td>16.0</td>
<td>6.9</td>
<td>7.2</td>
<td>27.2</td>
<td>57.3</td>
</tr>
<tr>
<td></td>
<td>Valuation</td>
<td>$0.31</td>
<td>$0.14</td>
<td>$0.14</td>
<td>$0.53</td>
<td>$1.12</td>
</tr>
<tr>
<td><strong>Asthma Exacerbation (6 – 18)</strong></td>
<td>Incidence</td>
<td>755.3</td>
<td>298.9</td>
<td>286.4</td>
<td>1244.4</td>
<td>2585.0</td>
</tr>
<tr>
<td></td>
<td>Valuation</td>
<td>$0.15</td>
<td>$0.06</td>
<td>$0.06</td>
<td>$0.25</td>
<td>$0.51</td>
</tr>
<tr>
<td><strong>HA Cardiovascular (18 – 99)</strong></td>
<td>Incidence</td>
<td>2.8</td>
<td>1.2</td>
<td>1.5</td>
<td>4.8</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>Valuation</td>
<td>$0.11</td>
<td>$0.05</td>
<td>$0.06</td>
<td>$0.19</td>
<td>$0.40</td>
</tr>
<tr>
<td><strong>HA Respiratory (18 – 99)</strong></td>
<td>Incidence</td>
<td>1.0</td>
<td>0.4</td>
<td>0.5</td>
<td>1.7</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>Valuation</td>
<td>$0.02</td>
<td>$0.01</td>
<td>$0.01</td>
<td>$0.04</td>
<td>$0.08</td>
</tr>
<tr>
<td><strong>Nitrogen dioxides (NO₂)</strong></td>
<td>Incidence</td>
<td>8.3</td>
<td>4.8</td>
<td>5.5</td>
<td>13.5</td>
<td>32.0</td>
</tr>
<tr>
<td><strong>HA Asthma (0 - 29)</strong></td>
<td>Valuation</td>
<td>$0.14</td>
<td>$0.08</td>
<td>$0.09</td>
<td>$0.22</td>
<td>$0.53</td>
</tr>
<tr>
<td><strong>HA Asthma (30 - 99)</strong></td>
<td>Incidence</td>
<td>7.7</td>
<td>4.8</td>
<td>5.9</td>
<td>12.8</td>
<td>31.2</td>
</tr>
<tr>
<td></td>
<td>Valuation</td>
<td>$0.13</td>
<td>$0.08</td>
<td>$0.10</td>
<td>$0.21</td>
<td>$0.52</td>
</tr>
</tbody>
</table>

Notes:
1. HA denotes Hospital Admissions.
2. Monetary values are in millions of 2010 $. 
3. The age range of people affected is shown in parentheses.

4.4 Health Impact Results

For our pollutant dispersion analysis, we assumed hourly emission rates from port trucks to be constant over the year, although under PierPASS off-peak shifts take place four nights per week (Monday through Thursday from 6:00 p.m. to 3:00 a.m.) with an additional shift on the weekend (Saturdays from 8:00 a.m. to 6:00 p.m.), for a total of 5 off-peak shifts per week. To account for the lack of 2 off-peak shifts during a week, we followed [17] and scaled down health impact results by a 5/7 factor.

Table 4 summarizes aggregated health impacts from PM₂.₅ and NO₂ exposure for health outcomes for which epidemiological information is available for our target population (Los Angeles County residents). All results are in 2010 dollars and the average value of a statistical life in 2010 is approximately $6.95 million. It shows that the combined health costs of PierPASS exceed $438 million annually and are driven by excess mortality resulting from exposure to PM₂.₅, with just under 63 cases per year on average representing close to $434 million and over
99% of estimated health costs. Chronic Bronchitis is a distant second with 57.3 extra cases and an annual cost of $1.12 million. However, the health outcome associated with PierPASS that affects the most people is asthma exacerbation with an extra 2585 cases annually from exposure to PM$_{2.5}$, and 63.2 additional cases annually from exposure to NO$_2$.

In addition, because of changes in meteorological conditions, the largest impacts of PierPASS are experienced during the fall season with 47% of estimated health costs, and the smallest health impacts are experienced during the spring with only 12.4% of estimated health costs. Note, however, that only the magnitude of these numbers is meaningful because our models do not reflect seasonal variations in drayage truck activity. Moreover, our calculations do not cover all possible health outcomes or all age groups because of limitations in available epidemiological data.

5. CONCLUSIONS

The objective of this paper was to estimate some environmental and health impacts of the PierPASS program, which was implemented in 2005 at the SPBP complex to mitigate the congestion and air pollution resulting from freight operations. Our study area extends from downtown Los Angeles to the gates of the SPBP but it excludes drayage operations inside of the Ports because of data limitations. To obtain better estimates of congestion and of air pollutant emissions, we combined a microscopic traffic simulation model (TransModeler) with EPA's MOVES model. After calibrating our model using a dynamic origin-destination demand estimation algorithm for a representative day in 2005, we ran 24-hour simulations for two scenarios: (1) a baseline, pre PierPASS scenario; and (2) a post-PierPASS scenario obtained by shifting drayage truck traffic from peak to off-peak hours based on observed data. Vehicular emissions of NO$_2$ and PM$_{2.5}$ were then generated from detailed vehicle trajectories using MOVES, dispersed using CalPuff, and the resulting health impacts were estimated using EPA's BenMAP model. To our knowledge, our paper is the first one to analyze a major shift in freight delivery using this approach.

We found that PierPASS had little impact on congestion in our study area. Moreover, PierPASS only resulted in small reductions of emissions of pollution (-0.47% for NO$_2$ and -0.68% for PM$_{2.5}$). The main impact of PierPASS on emissions is an increase in nighttime emissions of NO$_2$ and PM$_{2.5}$ (by 19.41% and 19.52% respectively) and a decrease in daytime emissions of these pollutants (by 5.02% and 4.93% respectively). Because of boundary layer effects, these increases in nighttime emissions led to increases in pollutant concentrations during the night but also during the day. These increases are highest during the fall and smaller during the spring. As a result, we found that PierPASS created annual health costs in excess of $438 million, which are overwhelmingly due to excess mortality from PM$_{2.5}$ exposure, although the most common health outcome is asthma exacerbation.

There are several limitations to our study. First, our microscopic traffic simulation model considers only a representative day without traffic disruptions caused by accidents. Thus possible changes in emissions and health impact caused by accidents resulting from shifting port truck deliveries from day-time to night-time are not captured. Second, our analyses ignore emission reduction that took place within the ports because of a lack of information about trucks movements within the ports before and after PierPASS; a reduction in drayage trucks queueing within the ports could have substantial health benefits that could partly offset our estimated health costs in our study area. A third limitation is the lack of epidemiological data for mortality.
due to PM$_{2.5}$ exposure for people under 30 years in Los Angeles County, and very limited
epidemiological studies on NO$_x$ exposure. Addressing these limitations is left for future work.

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