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A Preliminary Analysis of the Environmental Impacts of the Clean Truck Program in the Alameda Corridor, CA

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1   **ABSTRACT**
2   The San Pedro Bay Ports (SPBP) of Los Angeles and Long Beach in Southern California is one
3   of the largest port container complexes in the world, and the largest one is the United States. To
4   decrease the air pollution associated with port operations, a number of measures have been
5   adopted, including the Clean Trucks Program, which was introduced in 2008 to clean up the fleet
6   of drayage trucks serving the SPBP. The objective of this paper is to quantify the reduction in
7   emissions attributable to the Clean Trucks Program, with a focus on Nitrogen Oxide (NO_x) and
8   Particulate Matter ($PM_{2.5}$). Our approach is innovative as it relies on micro-simulation to capture
9   the link between congestion and pollutant emissions. We find that the Clean Trucks Program
10   could contribute significantly to the emissions of NO_x (~27%) and $PM_{2.5}$ (~25%) for all the
11   freeway traffic in our study area. These preliminary results suggest that the Clean Trucks
12   Program is promising, but its cost-effectiveness should be analyzed.

INTRODUCTION

1 The San Pedro Bay Ports (SPBP) of Los Angeles and Long Beach in Southern California
2 comprise one of the largest container port complexes in the world. Although the SPBP's
3 contribution is essential to both the state's and the nation's economies, increasing congestion and
4 air pollution have been affecting the daily lives of those who reside, work, and attend school near
5 the SPBP and along the freeways used by drayage trucks. According to the 2007 emission
6 inventory, SPBP related Heavy Duty Vehicles contribute 35% of $PM_{2.5}$ (particulate matter with a
7 diameter ≤ 2.5 μm), 35% of NO_X (nitrous oxides), and 57% of CO (carbon monoxide) of port-
8 related emissions in the South Coast Air Basin and within the SPBP boundary [1].
9 Widespread concerns about air pollutants have lead state and local government
10 organizations including the California Air Resource Board (CARB) and the Southern California
11 Association of Governments (SCAG), along with the SPBP, to propose strategies for reducing
12 air pollution generated by the movement of goods in and out of the SPBP complex. One of these
13 strategies is the Clean Trucks Program (CTP), which started in October 1, 2008, with a ban on all
14 pre-1989 trucks. Its goal is to reduce air pollution from harbor trucks by more than 80 percent by
15 2012 by replacing older and damaged trucks, retrofitting truck engines, or installing Diesel
16 Particular Filter (DPF) [2].
17 The main question this paper addresses is: "How effective has the Clean Truck Program
18 been at reducing air pollutants?" In particular, we focus on Nitrous Oxide (NO_x) and Particulate
19 Matter (PM), which are major sources of concern for the health of local residents. NO_x, which in
20 our case is mostly NO_2, is an ozone precursor; PM can cause premature respiratory and
21 cardiovascular deaths as well as hospital admissions for a variety of ailments [3]. Exposure to air
22 pollutants results in both long-term and short-term health effects. Short-term effects include eye,
23 nose and throat irritation, bronchitis and pneumonia [4, 5]. Long-term health effects include lung
24 cancer, chronic respiratory and heart disease; it can also cause premature death and degrade the
25 health of elderly people.
26 The amount of air pollutants emitted into the atmosphere by trucks depend on vehicle
27 speed, miles traveled, acceleration and deceleration rates, which are ignored by planning models
28 such as EMFAC or MOBILE. We therefore rely on micro-simulation to model traffic in the
29 Alameda corridor, between the SPBP and downtown Los Angeles (see Figure 1), to obtain more
30 realistic estimates of traffic congestions and the resulting air pollution.
31 This paper first summarizes some air pollutant reduction programs that are relevant to the
32 Clean Truck Program. Next, we provide some background information about the Clean Truck
33 Program before discussing our assumptions and our methodology. We then summarize results
34 from our analyses before presenting concluding remarks. To the best of our knowledge, this is
35 the first paper that attempts to examine the environmental benefits of the Clean Truck Program
36 using micro-simulation

REVIEW OF SOME RELEVANT PAPERS

A review of the transportation literature did not turn out any other paper that relies on traffic
micro-simulation to analyze the environmental benefits of a measure like the Clean Truck
Program. Micro-simulation (we used TransModeler) allows us to quantify the impact of vehicle
interactions (such as lane-changing, accelerations and decelerations) on the emissions of various
pollutants.

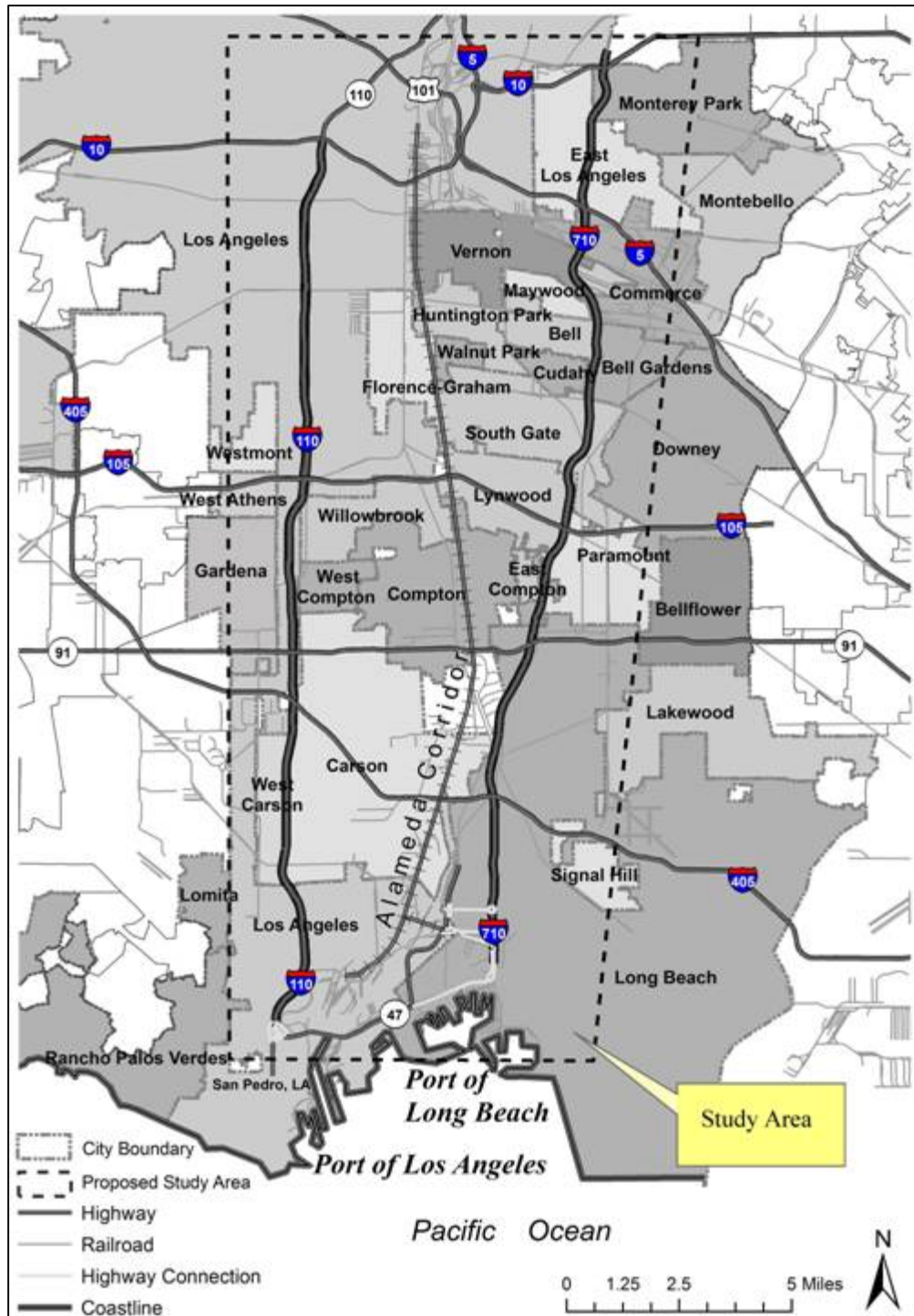**Figure 1. Map of study area.**

Similar to papers dealing with changes in fuel efficiency standards, such as the Corporate Average Fuel Economy (CAFE) standards, this paper addresses the change in emissions from a change in policy. The policy, in this case, is stricter emissions standards for trucks that service the San Pedro Bay Ports. Critics may argue that implementing stricter emission standards is not a first best approach and that implementing higher fuel taxes instead would reduce emissions

more by changing travel behavior [6]. However, increasing the fuel tax in this case, will likely not affect port truck traffic as the demand for transporting goods is largely inelastic. In addition, the primary goal of the Clean Trucks Program is to reduce the emission of air pollutants from drayage trucks and not to tackle port truck congestion. Implementing emission standards by government intervention provides an incentive that would otherwise not exist under free market conditions [7].

A number of published papers study the benefits of reducing emissions in other parts of the world. Using a simulation model (MIMOSA), Schrooten et al. [8] analyze scenarios for reducing air pollutants (including PM) in the Belgian region of Flanders. The most intensive scenario in their paper decreases PM emissions by 44% up to the year 2010. The marginal costs for a number of emission reduction standards are relatively high, and it appears that equipping heavy-duty trucks with particulate filters is the most cost-effective approach. Retrofitting buses is less effective than retrofitting heavy-duty trucks because buses travel relatively fewer miles each year. Replacing older heavy-duty trucks and buses by hybrids or biodiesel vehicles have higher costs than benefits. Previous studies performed in London show approximately the same.

Jansen and Denis [9] on the other hand compare four policies that aim at reducing carbon emissions: (1) an emissions cap, (2) a CO_2 purchase "feebate," (3) a combination of "feebate" with a CO_2 tax, and (4) instruments directed at other policies, such as road pricing and a NO_x tax. They rely on the software EUCARS to conduct a welfare analysis. They find that any policy that involves a fuel tax has a greater impact on reducing fuel emissions. A fuel tax is also welfare improving since it reduces emissions while raising revenues. The authors then evaluate an equivalent tax on NO_x in combination with other policies. Results are similar: the combination of a tax on NO_x emissions with a "feebate" has the greatest impact at reducing emissions.

Also of interest, Miraglian and El Khouri [10] performed a cost benefit analysis of the addition of stabilized ethanol/diesel blend into the bus and truck fleet of the Greater Metropolitan Area of Sao Paulo. Their paper incorporates the health benefits from a reduction in air pollutants using health benefit parameters published by the EPA. They find that adding the blend improves air quality and yields a net benefit of approximately US$ 2.85 billion.

BACKGROUND INFORMATION ON THE CLEAN TRUCK PROGRAM
The Clean Truck Program is a joint project of the Ports of Long Beach and Los Angeles. Its goal is to reduce air pollution from drayage trucks by 80% by year 2012, mostly by modernizing the fleet of drayage vehicles [11]. It is well known that drayage trucks are a large contributor to air pollution in the Southern Basin [12]. The Clean Truck Program bans pre-1989 trucks, as well as trucks that do not meet 2007 Emission Standards from servicing the port area. It also provides incentives in the form of grants, subsidies and leases, to buy newer and cleaner drayage trucks that meet both state and federal emission standards. Funds from both Proposition 1B and the Clean Truck Fee are used to help finance vehicle fleet upgrades. For compliance purposes, all truck operators are required to install radio frequency identification tags (RFID) on their trucks. They must also register their vehicles with the Drayage Truck Registry, a database that keeps information on truck age, model, year, engine year, and fuel type. Thanks to RFID tags, the Drayage Truck Registry also collects information about movements in and out of the port area.

The Clean Truck Program is divided into two phases. The first phase bans any truck equipped with a pre-1989 model year engine from entering the ports after December 31, 2009. Trucks engines that are newer than 1989 but that are not in compliance with the 2007 Emission Standards, established by the California Air Resource Board and the Environmental Protection

Agency, are subject to the Clean Truck Fee, which fee is currently set at $35 per twenty- foot equivalent container. Trucks that meet the 2007 Emission Standards are exempt from that fee if they were purchased with private funds (as opposed to funds from Proposition 1B).

The second phase of the Clean Truck Program starts after December 31, 2013; it bans from the SPBP any truck equipped with a pre-1994 model year engine, or any truck that is not in compliance with the 2007 Emission Standards.

The Clean Truck Program began collecting the Clean Truck Mitigation Fee on February 18, 2009, despite legal challenges from both the American Trucking Association and the Federal Maritime Commission that delayed its implementation (its original starting date was October 1, 2008 [13]). On July 28, the American Trucking Association filed a lawsuit about this fee but the judge dismissed the case and the program was allowed to move forward. Then in the fall of 2008, the Federal Maritime Commission (FMC) issued an injunction on parts of the program with the Supreme Court, Washington D.C. District. Under the Federal Shipping Act of 1984, the FMC has the right to intervene when it thinks unfair competitive restrictions or unduly expensive mandates have been placed on international commerce.

The FMC claimed that by requiring truck drivers to register their trucks through a trucking company, the program would reduce competition among owner-operated truck drivers. The FMC also argued that implementing a Clean Truck Fee and subsequently requiring truckers to change their vehicles to cleaner-burning trucks would substantially increase transportation costs and drive trucking companies out of business. The Clean Truck Program is working closely with trucking companies to ensure that truck drivers are eligible for up to 20% of the cost of replacing their vehicle. Proposition 1B allows $50,000 per truck in the form of grants, loans, and leases to partially fund upgrades to new and cleaner trucks. With changes to the clean truck fee and with the appointment of Joseph E. Brennan under the new administration, in June 2009 the FMC decided to drop the lawsuit against the Clean Truck Program.

The 2007 California Emission Standards
It is useful at this point to briefly review the 2007 California emission standards. These criteria were established according to engine year by the California Air Resource Board. Note that the toughest restrictions after 2007 apply to both NO_x and PM emissions.

Table 1. Regulations for Heavy-Duty Diesel Truck Engines [g/bhp*hr]

Year	HC	CO	NO_x	PM
1988	1.3	15.5	10.7	0.60
1990	1.3	15.5	6.0	0.60
1991	1.3	15.5	5.0	0.25
1994	1.3	15.5	5.0	0.10
1998	1.3	15.5	4.0	0.10
2007 and later	1.3	15.5	0.20	0.01

On and after 2007, the limit on non-methane hydrocarbons is 0.14 g/bhp-hr In terms of grams per mile, this translates approximately to the following emission limits:

| Table 2. Weight-based emission limits for heavy-duty diesel trucks [grams/mile]			
Vehicle weight	**HC**	**NO$_x$**	**PM**
8,500-10,000 lbs	0.20 g/mi	0.02 g/mi	0.195 g/mi
10,000-14,000 lbs	0.40 g/mi	0.02 g/mi	0.230 g/mi

Vehicle Fleet Distribution

To estimate the benefits from the Clean Truck Program, it is essential to know key characteristics such as fuel and engine age. These data come from two sources. The first source is a study produced by the California Air Resource Board. The second source is the Port of Long Beach Drayage Truck Registry. Figure 2 (top panel) depicts the age distribution for port trucks predicted up to the year 2014 by the 2006 CARB study (13). As a baseline, this CARB study also estimated the 2005 vehicle fleet distribution based on available data. This case is labeled as "Baseline 2005." Note that for the 2005 baseline, most trucks servicing the SPBP are from model years 1994 to 2002. Older trucks (pre-1993) make up approximately 28 percent of the total, while newer ones (2003 and more recent) make up less than 10 percent of the total.

The truck age distributions for 2010, 2011, and 2014 assume that both phases of the Clean Truck Program have been implemented and that most truck drivers will install particulate filters instead of purchasing new trucks to meet the Clean Truck Program requirements.

For the year 2010, which is denoted in blue, 87.7 percent of trucks servicing the port area are assumed to have model year 1994-2002 engines retrofitted to meet the 2007 emission, 10.4 percent are model year 2003-1006, 1.7 percent are model year 2007-2009, and the balance (less than 1 percent) are model year 2010. As the Clean Trucks Program matures (red and green bars), a slightly higher percentage of trucks is assumed to be model engine year 2010 and above. Although knowing the truck age distribution is informative, it is more important to know the distribution of engine years for analyzing emissions.

As shown on the bottom panel of Figure 2, in 2005 (Baseline Scenario) approximately 28 percent of port trucks were equipped with pre-1993 model year engines, roughly 63 percent had 1994-2002 engines, and slightly less than 10 percent had 2003-2006 model year engines. As the Clean Trucks Program progresses, dust particulate filters are installed, engines are retrofitted, and old trucks are replaced with newer trucks, so by the year 2010 (denoted in blue), most trucks are assumed to meet 2007 emission standards. Hence, for modeling purposes, trucks that are CARB 2007 compliant are assumed to be engine model year 2007. In particular, in year 2010, 2003-2006 model year engines are assumed to be 2007 emission compliant as they were retrofitted or equipped with dust particulate filters; moreover, slightly less than two percent of trucks will have 2007-2009 model year engines and less than one percent will be brand new trucks (model year 2010 and above). As the Clean Trucks Program moves forward, a higher percentage of trucks is assumed to have model year engines 2010 and above. For the year 2014 (denoted in green), 99 percent of trucks is assumed to be engine model year 2007-2009, and slightly less than 1 percent is assumed to have 2010 model year (and above) engines.
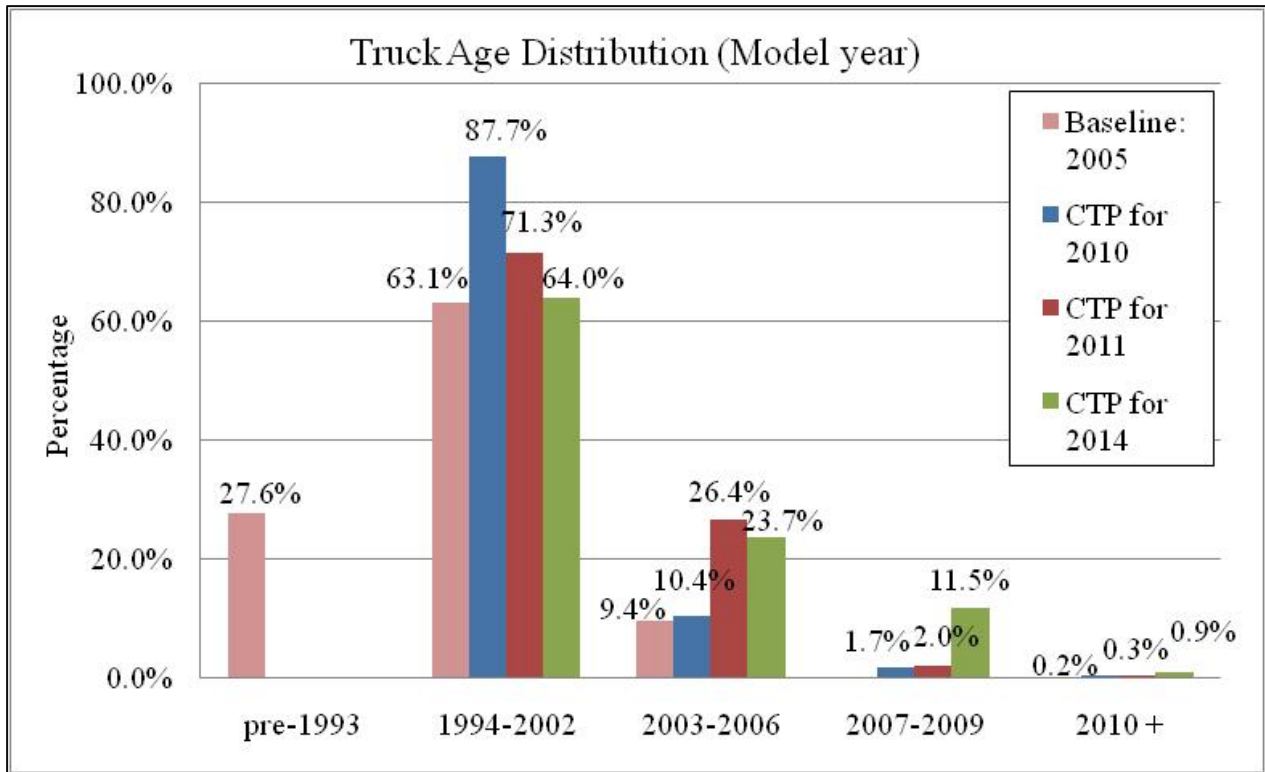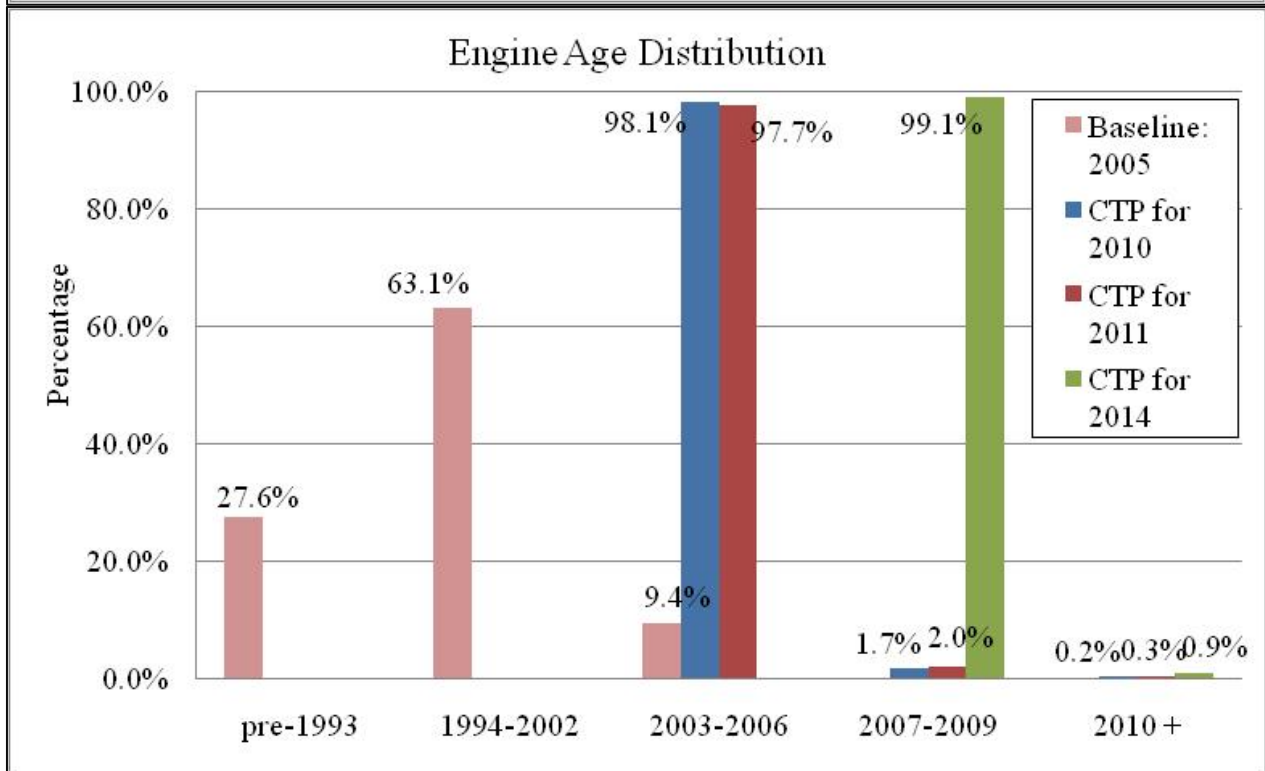
Figure 2. Truck Age and Engine Model Year Distributions

Figure 3 depicts the predicted age distribution of trucks from the CARB 2006 study, and the actual truck age distribution servicing the ports in May of 2009 based on the Drayage Truck Registry Database. The 2007-2009 spike suggests that a surprisingly higher amount of new

trucks were ordered and replaced than was originally predicted. This suggests that a slightly
higher than expected proportion of truck operators opted to replace their old trucks for new
trucks, as opposed to installing dust particular filters or retrofitting engines. This may be due to
the expected compensation from Proposition 1B funds for replacing trucks.
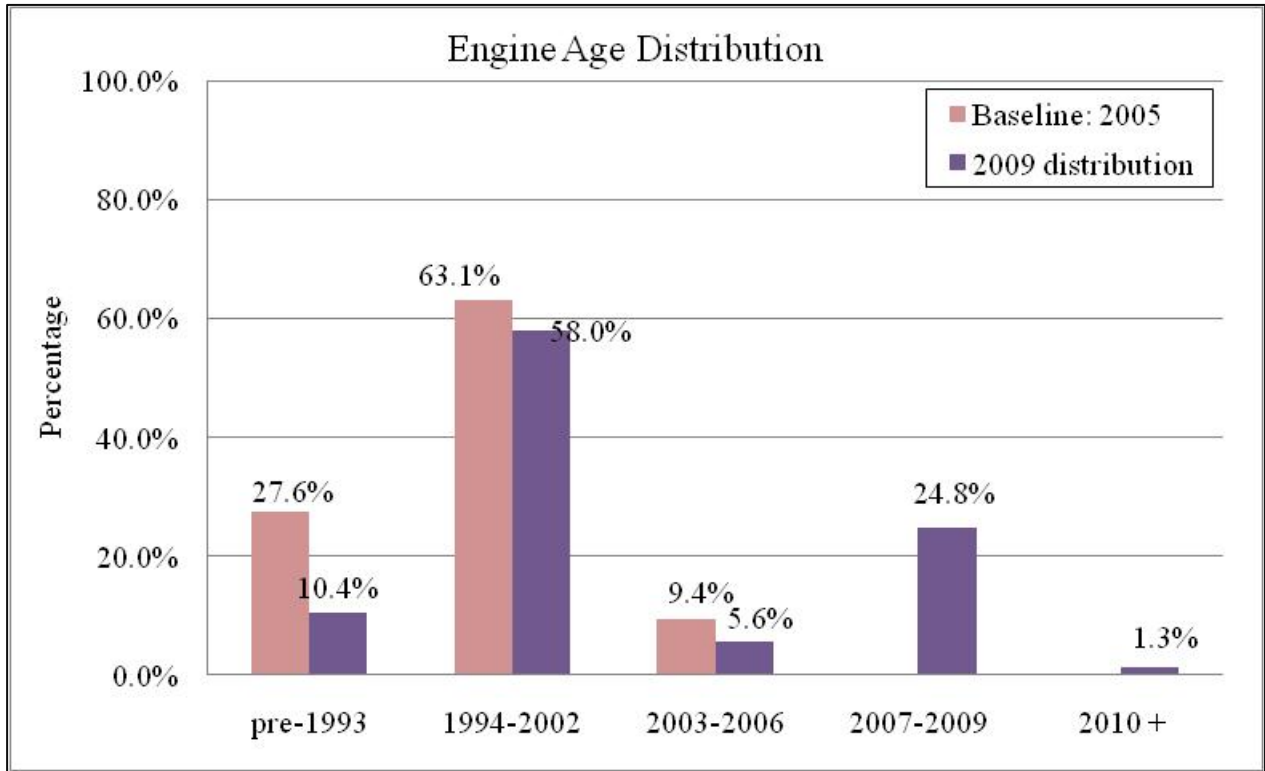
Figure 3. Engine Age Distribution (Baseline versus Actual)

For simplicity, we assume that trucks whose engine was retrofitted to meet the 2007
standards perform just like 2007 model year trucks from the point of view of emissions. This is
likely a lower bound on emissions as truck emissions also depend on truck aerodynamic
characteristics, for example.

For future reference, it is also useful to summarize the characteristics of the current fleet
of drayage trucks serving the SPBP based on information contained in the Drayage Truck
Registry. In May 2009, there were approximately 15,000 trucks registered with the Port Drayage
Registry. Approximately 22 percent of these trucks were in compliance with the 2007 Emission
Standards; trucks that are not in compliance with the 2007 Emission Standards are subject to the
Clean Truck Program fee, which helps finance newer clean trucks. Table 3 shows the
distribution of port trucks by year and reported engine fuel type, which is useful for estimating
emission rates for the actual 2009 vehicle fleet. It is important to note that the Clean Truck
Program does not mandate a specific fuel type; this is left to truck operators. Due to the high cost
of natural gas trucks, and the unavailability of hybrid-diesel trucks, most trucks servicing the port
have diesel engines; most of these are in compliance with the 2007 emission standards.

Table 3: Port Truck Numbers by Fuel Type		
Fuel Type	**Count**	**Percent**
BioDiesel	64	0.41
Diesel	15,208	97.83
Natural Gas	259	1.67
Other Alt. Fuel	13	0.08
Unleaded	2	0.01
Total	**15,546**	**100.00**

To estimate the benefits of replacing older engines with newer clean engines, we rely on the information contained in the tables above. Traffic levels are held constant to 2005 levels since predicted traffic levels for future years are very uncertain. Hence, our emission reduction estimates should be taken as the benefits from implementing the Clean Truck Program in 2005.

Study Area
The San Pedro Bay Ports (SPBP) of Los Angeles and Long Beach in Southern California is serviced by several freight corridors. Although port trucks also use surface streets (e.g., to access local railyards), we focus on emissions from the freeway network. Our study area is centered on the I-710 the I-110 freeways, over a 22 miles stretch extending from the SPBP to downtown Los Angeles; these two freeways are crossed by four major freeways (the I-5, 1-10, SR-60, and SR 91). Our study area is presented in Figure 1.

METHODOLOGY
Our approach is similar to the one used in (15). An overview of our methodology is presented in Figure 4. It hinges on two types of models: a microscopic traffic simulation model and a model to generate emissions of various pollutants. For this work, we selected respectively TransModeler and EMFAC (16, 17).

Tools
Microscopic traffic simulators are now widely used in traffic management, traffic operation/control, traffic impact studies, and assessments of Intelligent Transportation Systems (ITS) strategies. They are also starting to be used for evaluating vehicle emissions. They rely on a series of mathematical models, including for example, car-following models and lane changing models. They generate split-second-by-split-second movement of each network vehicle and their interactions, and produce trajectories essential for better modeling emissions.

For this study, we selected TransModeler because it is a leading representative of a new generation of microscopic traffic simulators. Moreover, vehicle trajectory in TransModeler can be easily processed to estimate emissions without any additional programming and TransModeler interfaces easily with Geographic Information System (GIS) data, which is useful for understanding emission dispersion (this is left for future work).

To estimate emissions, we rely on the EMFAC model, which was developed by the California Air Resources Board to calculate emission rates from on-road vehicles, from light-duty cars to heavy-duty trucks. EMFAC was chosen for its ability to incorporate results from micro-simulation, such as VMT and VHT and speeds, as well as for incorporating the characteristics of the fleet distribution of both passenger and heavy-duty vehicles. To fully exploit the information provided by microscopic traffic simulation, it would have been better to

1　use a microscopic emissions model such as CMEM (18), but CMEM cannot calculate PM
2　emissions, and it cannot estimate heavy duty truck emissions after the 2002 model year.
3
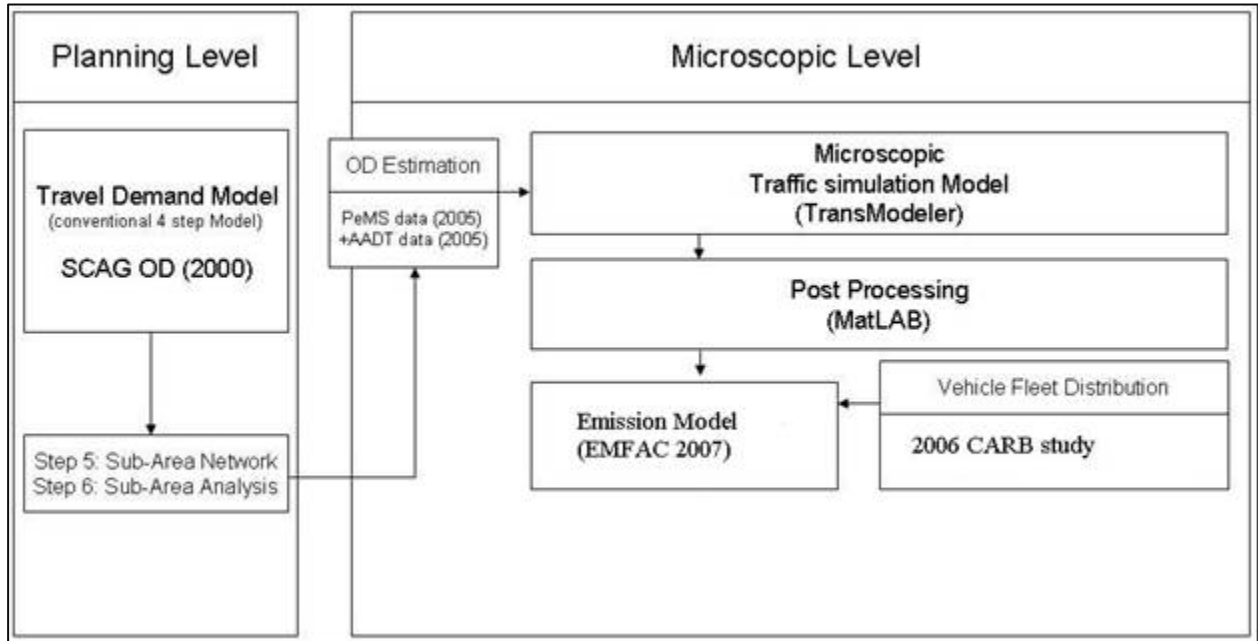
4
5　**Figure 4. Microscopic-level emission analysis framework**
6
7　**Data**
8　To mathematically represent our network in the traffic simulator, we first extracted coordinates
9　for our basic freeway layout from a GIS layer provided by Caltrans and obtained basic freeway
10　characteristics (such as the number of lanes and speed limits) from the Performance
11　Measurement System (PeMS) (19). For additional details, we relied on Google Earth.
12　　For traffic simulation, traffic OD (Origins and Destinations) demand inputs were
13　obtained from the 2000 Southern California Association of Governments (SCAG) traffic study,
14　which is the most comprehensive available for Southern California. To obtain OD demand
15　specifically for our network, sub-area analyses were performed in TransCAD: the sub-area
16　network was extracted from the 2000 SCAG data and OD demand was re-assigned.
17　　The OD demands were then adjusted to match traffic flow data every hour as measured
18　from PeMS loop detectors. When traffic flow data from PeMS were missing, we used AADT
19　data provided by Caltrans. For O-D estimation, a path-based algorithm was utilized (20), and the
20　commonly-accepted GEH statistic was selected for assessing goodness of fit:
21

22　$$GEH = \sqrt{\frac{(M-S)^2}{0.5(M+S)}},$$

23
24　where M measures traffic flow and S is simulated traffic flow; both are in vehicles per hour.
25　　To obtain an accurate good representation of network traffic conditions, we iterated until
26　the GEH statistic was below 5 (10) for at least 50% (85%) of our loop detectors.
27　　Obtaining reliable simulations of truck activities every business day of 2005 would be
28　very impractical, so after analyzing speed contours and total traffic volumes for 2005, we

1   determined that Wednesday, March 9th, 2005 was representative of weekday traffic conditions at
2   the SPBP complex. We therefore focused on obtaining calibrated simulation results for that day.
3   Based on overall traffic and SPBP truck traffic volumes, traffic conditions on our
4   network were classified as follows: 1) morning (from 7:00 AM to 9:00 AM); 2) midday (from
5   9:00 AM until 3:00 PM); and 3) afternoon (from 3:00 PM until 7:00 PM). These three categories
6   also correspond to the time periods adopted by SCAG in its OD estimation procedures. Night
7   traffic was not considered because during March of 2005, the SPBP was operating only from
8   8:00 AM until 6:00 PM. We considered the first hour (7:00 to 8:00 AM) to catch the early SPBP
9   truck traffic; likewise, we kept the last hour (6:00 to 7:00 PM) to capture the last flow of trucks
10 leaving the SPBP complex for the day.
11   Then for each time period we simulated the busiest and the least busy hour in order to
12 obtain upper and lower bounds for congestion and emissions. A sum of the emissions for the
13 three busiest hours weighted by the number of hours in each period gives an upper bound for
14 traffic emissions during the 12 hours during which port trucks are operating; likewise, the sum of
15 emissions for the three least busy hours weighted by the number of hours in each period (2 for
16 the morning period, 6 for midday, and 4 for the afternoon period) gives a lower bound for traffic
17 emissions during the 12 busiest hours of the day
18   Vehicles were categorized as light-duty vehicles (LDV), light-duty trucks (LDT),
19 medium-duty trucks (MDT), heavy-duty trucks (HDT), and port trucks (PORTS). Each hour
20 was simulated 30 times in TransModeler to obtain reasonable estimates of mean. Emission
21 estimates and fuel consumption rates were then calculated using EMFAC 2007 for each of the 30
22 trials.
23
24 **RESULTS**
25 Figure 5 (top panel) shows the change in NO_x emissions compared to the baseline 2005 scenario
26 for port trucks only. Based on information from the drayage truck registry, NO_x emissions are
27 reduced between 761 kg [upper bound] and 726 kg [lower bound]. Assuming that drayage trucks
28 operate year-round for 5 days a week, this represents between 189 and 198 metric tons for 2009.
29 Annual gains are maximized for 2014, where they ranged between 600 and 621 metric tons
30 respectively. Note that a lot needs to be accomplished between 2009 and 2014, as NOx
31 emissions from Port trucks need to decrease by a factor larger than 3.
32   The other pollutant of interest is $PM_{2.5}$, which shows a reduction ranging between 19.2
33 and 19.5 kilograms per day under current conditions (61.3 to 62.2 kg per day by 2014); see the
34 top panel of Figure 6. This translates into an annual decrease roughly equal to 5 metric tons for
35 2009 and 16 metric tons for 2009, which is quite substantial. Note that the difference between
36 the upper and the lower bounds are much tighter for $PM_{2.5}$ than for NO_x.
37   It is also instructive to look at results in percentage terms to assess the contribution of
38 Port trucks to overall traffic emissions on the freeways of our study area (see the bottom panels
39 of Figures 5 and 6). We see that emissions changes are very substantial for trucks alone: they
40 should reach approximately 78% for NO_x and a remarkable 96.5% for $PM_{2.5}$ by 2014. A lot
41 needs to be accomplished between now and 2014 (current reductions are approximately 25% for
42 NO_x and 30% for $PM_{2.5}$); it will require a transformation of the fleet of drayage trucks serving
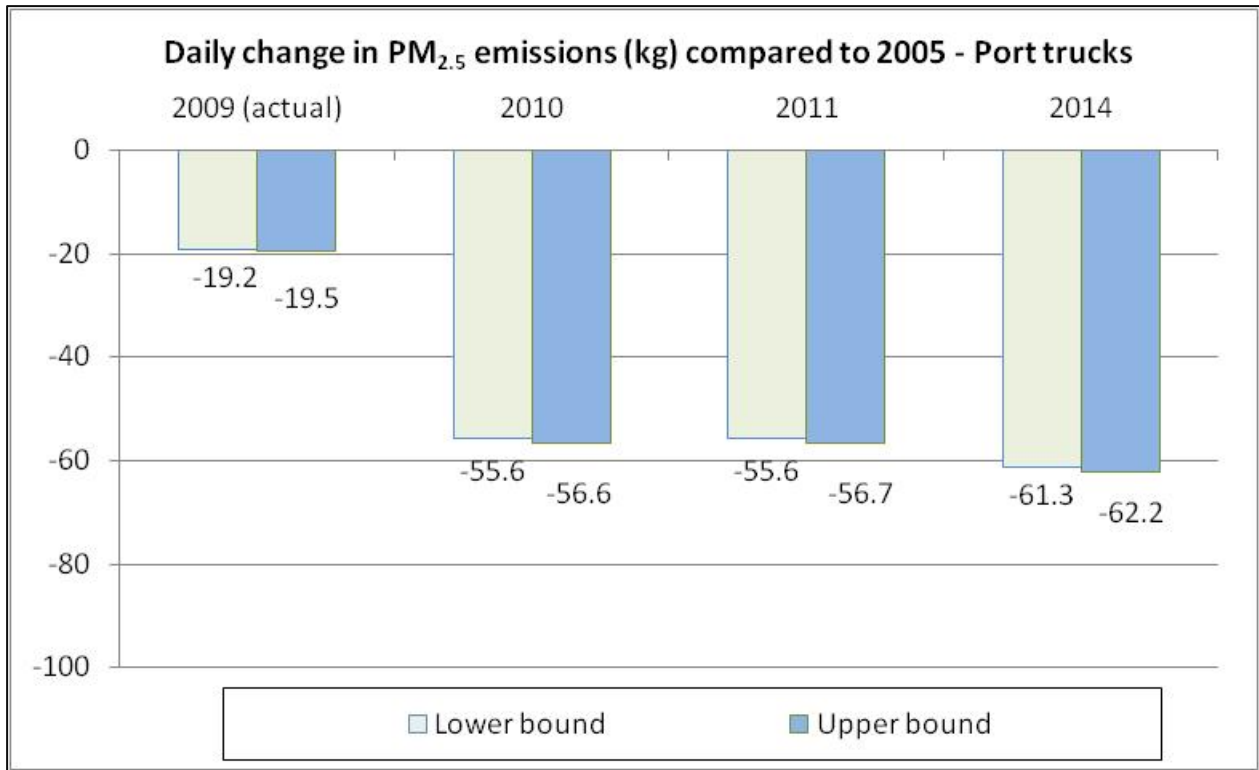43 the SPBP complex.
44
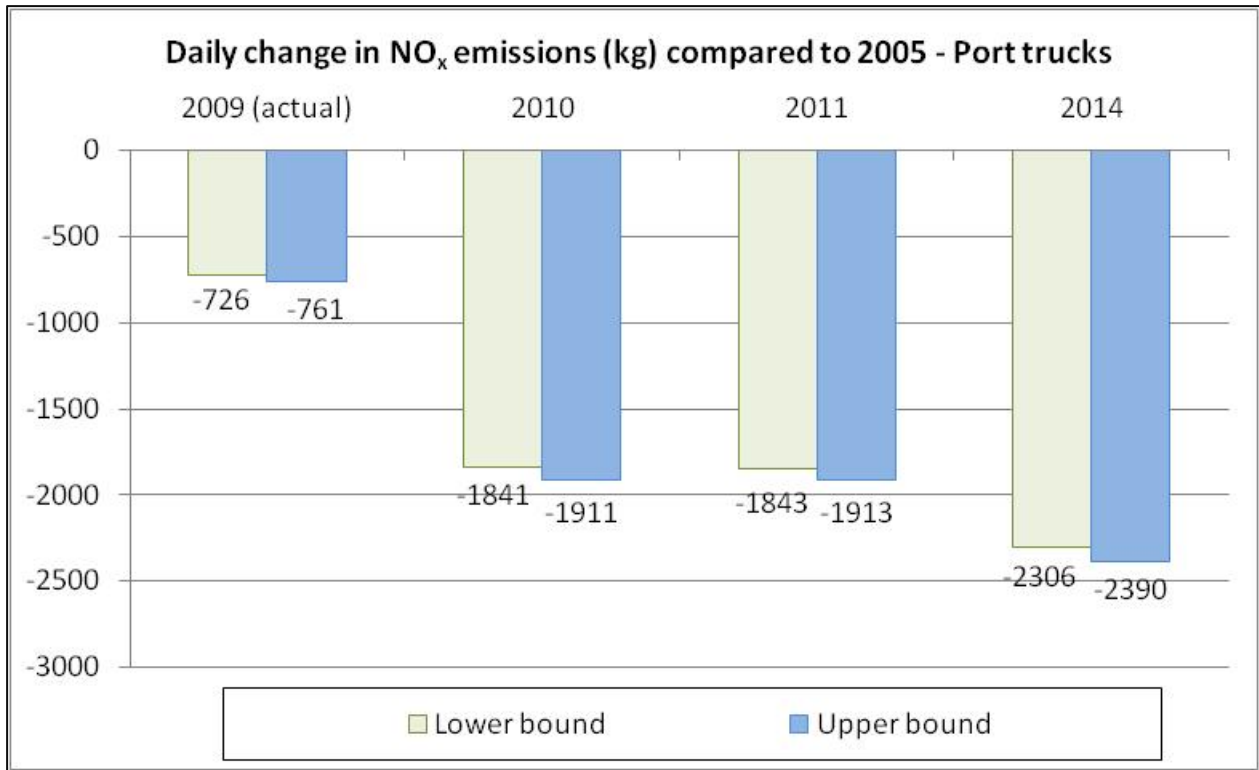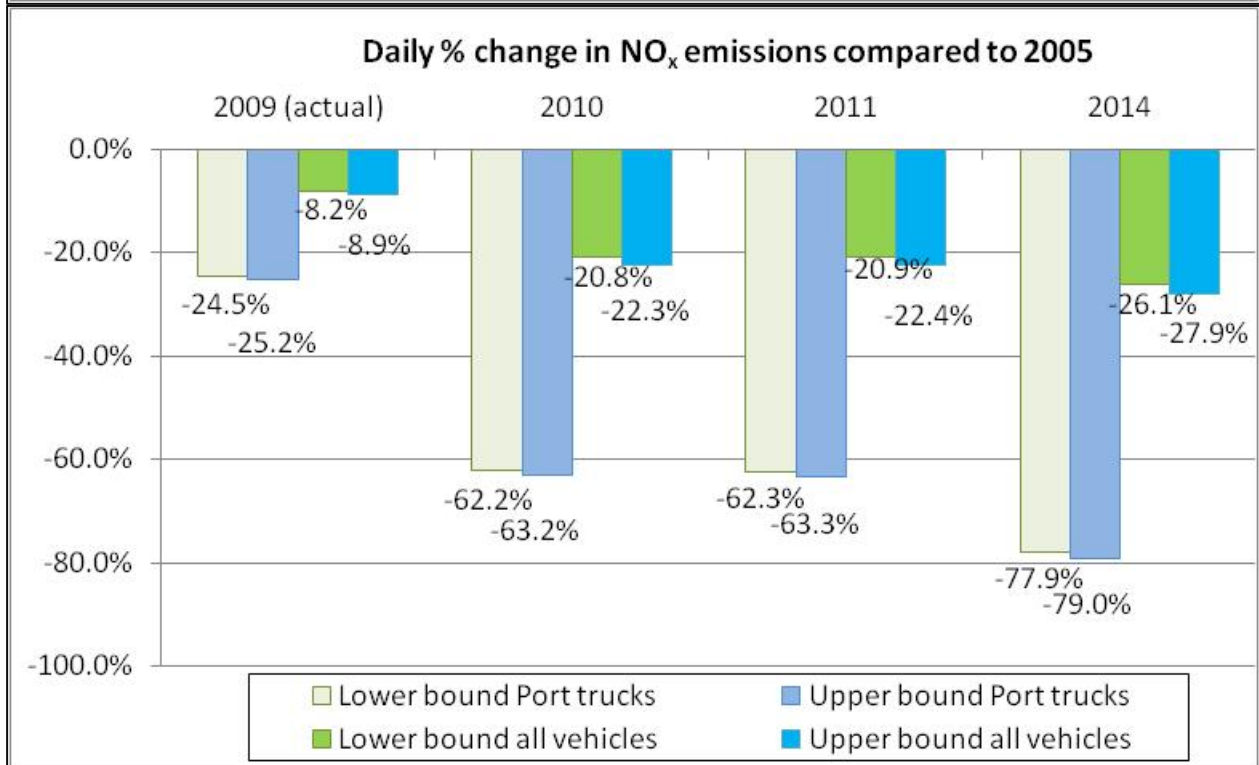
Figure 5. Change in NOₓ Emissions

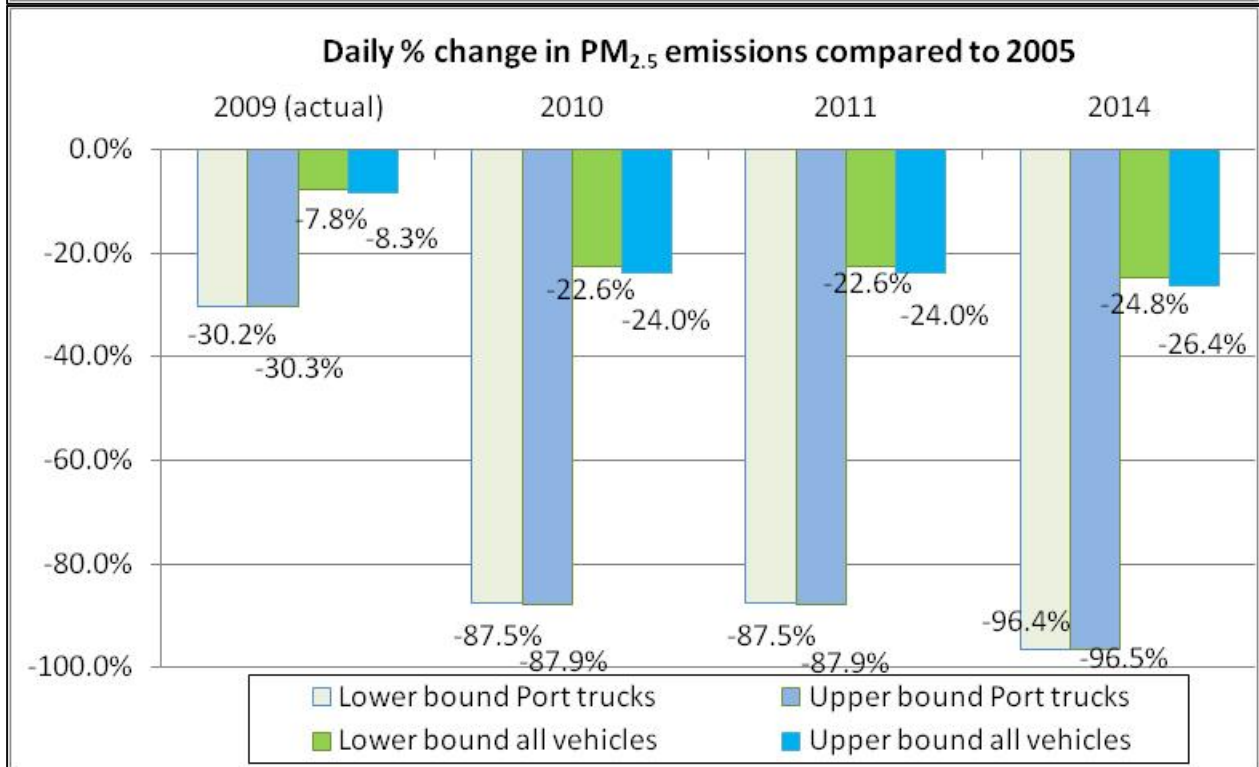**Figure 6. Change in PM$_{2.5}$ Emissions**

CONCLUSIONS

To our knowledge, this paper is the first to rely on micro-simulation in order to analyze the environmental performance of the Clean Trucks Program, which was launched by the SPBP to reduce emissions from drayage trucks and improve regional air quality. Our results indicate already substantial decreases in the emissions of NOx and $PM_{2.5}$ (in the order of 8.5% and 8% respectively). The fleet of drayage trucks will need to undergo a radical transformation, however, in order to achieve the stated goals of the Clean Trucks Program.

Although our methodology is general, these results are preliminary. Future work will extend our micro-simulation to account for a change in the hours of operation of the SPBP complex that took place in July of 2005. In addition, it would be of interest to analyze how the Clean Truck Program is affecting pollutant emissions from arterials in the vicinity of the SPBP complex, and to consider weekends, when fewer trucks on the road. Indeed, Lawson *et al.* [23] show that although NOx emissions are lower with fewer commercial trucks on the road, ozone concentrations may actually be higher on weekends. Finally, the health impacts of the Clean Trucks Program and the cost-effectiveness of this program should be explored.

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