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ABSTRACT

Escalating concerns about air quality in Southern California have led authorities of the Ports of Los Angeles and Long Beach, also known as the San Pedro Bay Ports (SPBP), to consider and adopt a number of emission mitigation measures. One possibility is to shift to trains some of the containers currently transported by drayage trucks. This alternative is attractive because it would decrease congestion and air pollution on the main freeways (I-710 and I-110) and arterials that serve the SPBP. In addition, it would increase road safety along the busy Alameda freight corridor between the SBBP and downtown Los Angeles. One drawback would be an increase in pollutant emissions from train operations in the Alameda corridor, but trains tend to pollute less than trucks per ton-mile and new federal regulations are tightening the emission standards for diesel locomotives. The goal of this paper is to quantify the net impact of such a modal shift on the emissions of PM and NOx, which are the two air pollutants of most concern in the SPBP area. Our analysis relies on microscopic simulation to better capture emissions resulting from stop-and-go traffic on the freeways serving the SPBP. We find that emissions of both NO_X and $PM_{2.5}$ can be significantly reduced by switching from drayage trucks to trains. This suggests that modal shift should be encouraged, especially if there is unused train capacity, and as long as it does not conflict with the shippers' interests.

INTRODUCTION

Escalating concerns about air quality in southern California have led the authorities of the Ports of Los Angeles and Long Beach, also known as the San Pedro Bay Ports (SPBP), to adopt a number of emission mitigation measures. Their goal was to improve the environmental performance of the SPBP complex so it could resume its expansion when the nation's economy starts growing again.

A number of state and regional agencies have been involved in this multi-year effort, including the California Air Resources Board (CARB) and the Southern California Association of Governments (SCAG). Clean-up plans, which cover a time horizon that extends until 2020, target emissions from ships, commercial harbor craft, locomotives, and trucks. In particular, truck emission reduction strategies include modal shifts from trucks to rail (*1, 2, 3*). This approach is expected to mitigate multiple environmental impacts associated with goods movement. First, it should reduce the volume of heavy truck traffic that currently contributes to local congestion and air pollution on major routes serving the SPBP complex, especially the I-710 and I-110 and the connected freeways (SR-47, I-405, SR-91, I-105, and I-5). Second, it will likely improve road safety along this busy freight corridor. And although shifting port traffic from drayage trucks to trains will likely increase pollution from train operations in the area, the net effect should still be positive because trains tend to be cleaner than trucks per ton-mile (*6*), and the U.S. EPA is tightening emissions standards for diesel locomotives (*1, 2, 3, 4, 5*).

The San Pedro Bay Ports Clean Air Action Plan (*7*) emphasizes the development of on-dock rail (where containers are transferred directly from a ship to a train), and statistics show that the share of on-dock use has gradually increased over time, from 15.9% in 2003 to 24.1% in 2006. According to the San Pedro Bay Ports Rail study update (*6*), each on-dock train can eliminate up to 750 truck trips, which reduces drayage-truck pollution and improves road safety; this is especially important for particulate matter (PM) emissions but it also impacts the emissions of other criteria pollutants. However, the development of on-dock rail alone will not eliminate the need for near-dock and off-dock trips and the related truck trips on local freeways and arterials.

Efforts by the SPBP complex to improve air quality appear to be bearing fruit. Indeed, a comparison between the 2007 and the 2005 emissions inventories for the Port of Long Beach shows that emissions of NO_x, SO_x, and hydrocarbons went down by 1%, 87%, and 17% respectively (*8, 9*), although PM and CO increased by 7%; this is still remarkable since the 9% increase in total Port TEU throughput that took place over that period was jointly accompanied by a 3% increase in total vehicle miles travelled (VMT) and a 43% jump in the tonnage handled by on-dock rail.

A few studies have analyzed the potential impacts of shifting container traffic from trucks to train, but they relied on planning models that are unable to capture the impacts on emissions of road congestion, as they only take into account average speed and vehicle miles traveled. For example, Fischer, Hicks, and Cartwright (*10*) proposed using macroscopic emissions analysis to evaluate truck trip reduction strategies including expanded on-dock rail facilities, a new near-dock rail intermodal terminal, and an inland rail shuttle service. More recently, using TransCAD and EMFAC2002, Park, Regan and Yang (*11*) found that shifting 10% of the heavy duty truck traffic to trains for the year 2000 reduced NO_x emissions by 35.8 kg/hr and cut PM emissions by 0.6 kg/hr; a 20% shift roughly doubled these amounts.

The objective of this paper is to present a more sophisticated analysis based on microscopic simulation of the traffic and air quality impacts of shifting some container traffic from drayage trucks to rail via on-dock services. Several authors, including Nesamani et al. (*12*) have shown that microscopic simulation (they relied on PARAMICS) provides better estimates of air pollution emissions as it models explicitly accelerations/decelerations, lane changing and merging/diverging, which are especially important in stop-and-go traffic. By contrast, static planning models ignore individual vehicle behavior, which leads to under-estimating pollutant emissions, and they do not account for link capacity, so they assign excessive traffic volumes to specific links in congested conditions resulting in emission over-estimates. As a result, estimates of emissions based on static planning models suffer from significant biases in different traffic conditions.

Our study area is shown on the left panel of Figure 1. It includes the main freeways that serve the SPBP complex along with the Alameda corridor, a key rail link to the Ports, and a number of rail yards. For microscopic simulation, we rely on TransModeler and we focus on 2005 as our base year. Our results quantify emissions gains and losses from drayage trucks and trains, with an overall system-wide reduction in emissions of NOx (1.0 %) and PM (0.4%).

This paper is organized as follows. First, we introduce some background information about the freight corridor linked to the SPBP complex and provide an overview of our methodological framework. We then summarize results of our analyses for both truck and train emission estimates. After discussing emission trade-offs resulting from shifting container traffic from trucks to trains we present some concluding remarks and offer some suggestions for future work.

STUDY SITE

The SPBP complex is served by two major freeways (the I-710 and the I-110) and by the Alameda rail corridor. To keep our study manageable while capturing a large share of the impacts of shifting some container traffic from trucks to trains, we selected a study area that extends from the SBPB complex to the edge of downtown Los Angeles (see Figure 1). It includes the two major freeways serving the SPBP complex (the I-710 and the I-110) along with major cross freeways, and the Alameda corridor rail link as well as the main rail yards in the area.

The SPBP complex is supported by three types of rail yards – on-dock, near-dock, and off-dock rail – defined by their proximity to the port terminals. On-dock rail yards are located within the marine terminal and are the focus of this study; they allow cargo to be transported without gate transactions and without truck dispatches. In this study, we analyze the environmental impacts of shifting freight from long-haul truck trips to on-dock trains. Analyzing near-dock and off-dock rail would be significantly more complex as it would also involve truck trips on surface streets for which traffic volumes are often unavailable. Along the coast of the SPBP, there are nine on-dock rail yards; five of them are located in the Port of Long Beach (Piers J, G, A, T, and Middle Harbor Terminal), and four are in the Port of Los Angeles (TICTF Shared on-dock, Pier 300, Pier 400, and WBICTF) (*6*); the right panel of Figure 1 locates these rail yards. The Pier B rail yard is considered a near-dock facility.

METHODOLOGY

To quantify the impacts of a modal shift on the truck emissions of $PM_{2.5}$ and NO_X, we relied on two types of models: 1) a microscopic traffic simulation model, and 2) a model to estimate the emissions of various pollutants. As a starting point, we analyzed the impacts of modal shift for the year 2005 primarily for consistency with CARB's 2006 emission reduction plan (*5*), but also to use results from previous analyses (*13, 17*).

For trucks, we adopted the modeling framework detailed in Lee et al. (*13, 14*); it is summarized on the left half of Figure 2. After deciding on a level of modal shift, we estimated a revised origin-destination (O-D) matrix and performed microscopic simulations using TransModeler (*15*) until a satisfactory match was obtained with traffic counts from the PeMS freeway performance measurement system used by the California Department of Transportation.

To estimate the resulting air pollutant emissions, we would have liked to rely on a microscopic emission model (either CMEM or VT-Micro), but we could not do so because of two of their current limitations: first, available microscopic emission models do not have emission factors for the most recent heavy duty trucks, and more importantly, these models are currently unable to model particulate matter (PM) emissions from heavy duty vehicles. To circumvent these limitations, we combined EMFAC2007 emission factors with detailed information about the trajectories of each simulated vehicle to obtain estimates of pollutant emissions (*16*). This application of EMFAC2007 is distinct from the macroscopic emissions estimation approach where emissions are calculated by applying emission factors to average traffic speed over a network. By contrast, we considered the speed of each vehicle on each link to take advantage of the information generated by microscopic simulation.

For trains, we relied on the methodology developed in Sangkapichai et al. (*17*); it is summarized in the right half of Figure 2. The number of trains necessary to haul the additional container traffic was calculated along with the corresponding number of locomotives; line-haul emissions were then estimated using emission factors and distance traveled in the Alameda corridor. Both line-haul and switching locomotives were assumed to belong to Tier 1 (see (*17*)). In addition, emissions from rail yard activities were scaled to reflect changes in train operations.

Results from train and truck analyses were then aggregated and compared to the baseline.

Obtaining reliable simulations of truck activities for every business day of 2005 would be extremely time consuming and impractical for several reasons: cleaning up detector data from PeMS takes time, and so does running a large number of simulations, especially in congested conditions. After comparing speed contours and total traffic volumes for 2005, we determined that Wednesday, March 9th, 2005 was representative of weekday traffic conditions at the SPBP complex. We therefore focused on obtaining calibrated simulation results for that day. Based on the volume of the overall traffic and also on SPBP truck traffic, traffic conditions in our network were classified as follows: 1) morning (from 7:00 AM to 9:00 AM); 2) midday (from 9:00 AM until 3:00 PM); and 3) afternoon (from 3:00 PM until 7:00 PM). These three time periods have distinct traffic (and truck volume) characteristics, and they correspond to the time periods adopted by SCAG in its OD estimation procedures (*3*). Night traffic was not considered because during March of 2005, the SPBP was operating from 8:00 AM until 6:00 PM. We considered the first hour (7:00 to 8:00 AM) to catch the early SPBP truck traffic; likewise, we modeled the last hour (6:00 to 7:00 PM) to capture the last flow of trucks leaving the SPBP complex for the day. Then for each time period we simulated the busiest and the least busy hour in order to obtain upper and lower bounds for congestion and for emissions.

This approach is summarized on Figure 3. A sum of the emissions for the three busiest hours weighted by the number of hours in each period gives an upper bound for traffic emissions during the 12 hours for which port trucks were operating; likewise, the sum of emissions for the three least busy hours weighted by the number of hours in each period (2 for the morning period, 6 for midday, and 4 for the afternoon period) gives a lower bound for traffic emissions during the 12 busiest hours of the day.

Description of Alternative scenarios

As a first step, emissions on a typical 2005 day were analyzed for the two following scenarios under the assumption of no demand changes from 2005 traffic levels:

- Scenario 1: Shift containers from trucks to trains to use half of the unused rail capacity; and
- Scenario 2: Shift containers from trucks to trains to use all of the unused rail capacity.

The proposed scenarios differ in the number of trucks affected by the switch to on-dock rail, which is specified by the volume of unused rail capacity in 2005. In 2005, the maximum capacity of on-dock rail was estimated at 3,832,499 TEUs or twenty foot equivalent container units (27% of total port throughput). Compared to the actual 2005 on-dock throughput (2,934,850 TEUs), 897,469 TEUs of unused capacity remained (*6*). To quantify the emission impact of a modal shift, it is necessary to consider a potential diversion rate between port heavy duty trucks and locomotives. The following describes the methods and assumptions by which TEUs were converted to trucks:

1) The number of port trucks to be shifted is produced by the share of hourly port truck distribution within the upper bound, or lower bound, respectively.

2) Only on-dock traffic is considered.
3) Unit trains have between 115 and 140 railcars, with each railcar carrying two stacked 40-foot containers (4 TEUs); given an industry average 90 % utilization rate, unit trains can be up to 8,000 feet long and carry between 414 and 504 TEUs.
4) Each train is assumed to have four Tier 1 locomotives.
5) Most trucks carry 40-foot containers, while some carry 20 foot containers; we assume that the average truck carries 1.8 TEUs.
6) Port trucks operate between 8:00 AM and 6:00 PM (Monday through Friday), and it takes an hour to clear port related truck traffic before and after operational hours.
7) Rail yards operate 24 hours a day, Tuesday through Saturday.

Based on assumptions 2), 5), and 6), the number of containers corresponding to unused capacity was converted to 1,870 trucks per working day. For locomotives, three additional trains for Scenario 1 and six trains for Scenario 2 are needed daily at on-dock rail yards from assumptions 3), 4), and 7). The corresponding values for each of the two scenarios are shown in Table 1.

TRAFFIC SIMULATION RESULTS

Due to the stochastic nature of microscopic traffic simulation, 30 runs for each scenario were generated in TransModeler to obtain estimates of mean emissions and to facilitate statistical testing (based on the central limit theorem). It is important to note that the traffic simulation results shown in Table 2 are based on total working hours for both the upper and the lower bounds.

Table 2 reports three performance measurement statistics for the baseline and the two scenarios considered: vehicle miles traveled (VMT), vehicle hours traveled (VHT), and average vehicle speed (Q, in mph) *(18)*. Vehicle class counts are also provided.

Comparing Scenarios 1 and 2 with the baseline, congestion decreases as Q is slightly higher and both VMT and VHT are lower, so traffic performance is improved. This is because heavy duty vehicles experience longer headway and inferior performance on grades during congested traffic conditions (*19*). This improvement in traffic congestion can be credited to a reduction in the percentage of port trucks among all vehicles. Compared to the baseline, the number of port trucks decreases by 0.02%-0.06% and by 0.1%-0.3% under Scenarios 1 and 2, respectively. Due to the higher share of port trucks in the lower bound case, modal shift impacts total traffic slightly more in that case. Although the percentage reduction in port trucks among all vehicles is relatively small, the emission reduction effect for overall $PM_{2.5}$ and NO_X is substantial (emission results are discussed below). Another notable impact is on VHT, which indicates that vehicle interactions such as stop-and-go and acceleration/deceleration are affected by port trucks.

EMISSION RESULTS

Emission Reductions Due to Port Truck Impacts

Port truck emission reductions related to each of the Scenarios are summarized in this section. To evaluate the statistical differences for each pollutant emissions between the baseline and each of the scenarios, two-sample z-tests were conducted at the $\alpha = 0.05$ significance level. These tests can be described as follows:

Two-sample z-test (Base Scenario vs. Alternative Scenarios)

$$H_0 : \mu_{\text{EmissionType,Base}} = \mu_{\text{EmissionType,Scenario}} \text{ vs. } H_1 : \mu_{\text{EmissionType,Base}} \neq \mu_{\text{EmissionType,Scenario}}$$

$$Z = \frac{(\hat{X}_{\text{EmissionType,Base}} - \hat{X}_{\text{EmissionType,Scenario}}) - (\mu_{\text{EmissionType,Base}} - \mu_{\text{EmissionType,Scenario}})}{\sqrt{(\sigma^2_{\hat{x}_{\text{EmissionType,Base}}} + \sigma^2_{\hat{x}_{\text{EmissionType,Scenario}}})}},$$

where $\hat{X}_{\text{EmissionType,Base}}$ is the average rate of each emission type by Scenario; $\sigma^2_{\hat{X}_{\text{EmissionType,Base}}}$ is the variance of each emission type by Scenario; and n is the number of observations (here n =30).

Figure 4 gives the percentage change for each pollutant under Scenarios 1 and 2 compared to the baseline, and it reports results of our hypothesis tests. Table 3 shows the average emissions rate by vehicle type for the baseline and for the scenarios considered.

From Table 3, we see that NO_X and PM emissions are dominated by heavy duty vehicles for all scenarios. In contrast, most CO and HC emissions come from passenger cars. Hypothesis tests comparing emissions under the baseline and under the alternative scenarios are statistically significant except for CO and HC emissions for total vehicle emissions in Scenario 1. On the other hand, results for Scenario 2, which involves removing more port trucks than Scenario 1, show that the decrease in the emissions of all pollutants is statistically significant and larger than for Scenario 1. In particular, Figure 4 (a) shows decreases of 1.4% for NO_X and 1.7% for $PM_{2.5}$ compared to overall emissions by eliminating port trucks that make up ~0.05% of total traffic in Scenario 1. We also find positive effects for Scenario 2. Likewise, considering only port trucks, Figure 4(b) shows significant reductions in all pollutants (~4.6%-5.6% for Scenario 1 and ~9.0%-10.2% for Scenario 2.)

The absolute emissions associated with all scenarios are described in Table 3. Some non-port vehicle emissions are not consistently reduced because reductions in port trucks in the alternative scenarios allow other vehicles to use the network, and therefore the increased VMT causes more emissions. Reductions in port trucks are not intended to increase the traffic of passenger vehicles, but they partly have that effect; we refer to this as secondary impacts. Although secondary impacts exist, our overall results show significant improvements in air quality. Emissions of NO_X and $PM_{2.5}$ generated by port truck represent 33.5% and 25.7% of the total for the upper bound of the base scenario, but they decrease to 32.3% and 24.6% under Scenario 1, and to 31.2% and 23.8% for $PM_{2.5}$ under Scenario 2.

Emission Changes for Locomotives

For estimating line haul emissions from locomotives, we followed the procedures presented by Sangkapichai et al. (*17*) to obtain daily emission rates for NO_X and PM_{10}. For consistency with the freeway emissions results, we calculated daily emissions rates and converted PM_{10} into $PM_{2.5}$ following CARB's size fraction data (see http://www.arb.ca.gov/ei/speciate/speciate.htm).

In Table 4 we summarize emission increases from increased rail operations. We do not consider the upper and lower bounds of traffic in the train movement analysis, but use average train traffic volumes. With the emission factors for locomotives and all the information mentioned above, Scenarios 1 and 2 respectively generate 1,897.8 kg/day and 2,009.4 kg/day of NO_x as well as 44.7 kg/day and 47.4 kg/day of $PM_{2.5}$. Details regarding the estimation of locomotive emissions are presented in Table 4.

Overall Impacts of Modal Shift

The emissions of on-road vehicles and locomotives are estimated on a daily basis during port and rail yard operating hours. Results are summarized in Table 5. For Scenario 1, NO_X emissions were reduced by approximately 150 kg from port trucks while the locomotives that carried the same amount of truckload freight produced 111.7 kg of NO_X, so the estimated net change in NO_X was approximately 40 kg. For the same scenario, the net reduction in $PM_{2.5}$ emissions is at most 0.8 kg. Reductions fro Scenario 2 are larger than those for Scenario 1 but emission reductions are not proportional since emission rates rely not only on VMT but also on traffic parameters such as speed. From the perspective of overall system-wide reduction, more significant benefits result from reducing NO_x emissions. Even considering secondary effects, the difference between reduced truck emissions and additional locomotive emissions is positive.

These results are persuasive enough to propose a modal shift strategy for mitigating truck emissions. This modal shift can also be expected to have an impact on the dispersion of air pollutants. Indeed, Wu et al. (*20*) report that pollutants such as NO_X and $PM_{2.5}$ are concentrated downwind immediately after their release, and they tend to accumulate in several areas that include residential and commercial facilities as well as public schools. Therefore, it is essential to assess not only daily impacts such as those shown in Table 5, but also longer term environmental impacts.

CONCLUSIONS AND FUTURE RESEARCH

The objective of this paper was to quantify the environmental impacts of shifting containers transportation from heavy duty diesel trucks to on-dock trains. We analyzed the impacts of modal shift on the freight corridor containing six different freeways and nine on-dock rail yards directly linked to the SPBP. In particular, we relied on microscopic simulation to capture detailed individual vehicle dynamics such as stop-and-go situations.

Results of two modal shift Scenarios with different port truck reductions were evaluated against our 2005 baseline year. Heavy duty truck-oriented pollutants such as NO_X and $PM_{2.5}$ were significantly reduced by taking port trucks off the road. System-wide emissions reductions were achieved due to a lesser gain in locomotive emissions. In particular, emission results include traffic-related benefits such as reduced traffic congestion and more stable speeds with smoother traffic characterized by fewer acceleration and deceleration. Our findings show that a modal shift has the potential to reduce emissions in the vicinity of the SBPB complex. The benefits of modal shift will be strengthened with the Rail Enhancement Program (REP) and the 2008 EPA emissions regulations for diesel locomotives; REP increases rail yard capacity so more containers can be handled, and the 2008 EPA emission regulations that gradually clean up locomotives will start to take effect in (*23*).

In a parallel effort, we are studying the impacts of the Clean Truck Program in the same study area. In the future, in order to better understand the impacts of port related heavy duty vehicles on neighboring communities, we will concentrate on local street emissions and we will strive to perform an overall assessment of air quality impacts of freight transportation at near-dock and off-dock rail yard locations.

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The List of Tables

TABLE 1 Number of Port Trucks to Be Shifted

Number of Port trucks to remove				Number of trains to add
Upper bound				
	Morning (7:00-8:00 AM)	Midday (2:00 - 3:00 PM)	Afternoon (5:00 - 6:00 PM)	Operation Hours (24hrs)
Hourly Port truck distribution (%)	10.0%	11.5%	7.0%	-
Scenario 1	95	107	66	3
Scenario 2	191	215	131	6
Lower bound				
	Morning (8:00-9:00 AM)	Midday (11:00 AM – noon)	Afternoon (6:00 - 7:00 PM)	Operation Hours (24hrs)
Hourly Port truck distribution (%)	10.2%	11.7%	6.5%	-
Scenario 1	93	110	61	3
Scenario 2	187	219	121	6

TABLE 2 Summary of Traffic Simulation Results (total working hours: 12hours)

		Upper bound			**Lower bound**		
		Baseline	**Scenario 1**	**Scenario 2**	**Baseline**	**Scenario 1**	**Scenario 2**
Vehicle Miles Traveled (VMT) (% difference compared to Baseline)		10,593,439	10,591,471 (-0.02%)	10,579,149 (-0.1%)	9,810,107	9,804,218 (-0.06%)	9,783,844 (-0.3%)
Vehicle Hours Traveled (VHT) (% difference compared to Baseline)		252,202	250,362 (-0.7%)	249,953 (-0.9%)	189,359	189,119 (-0.1%)	187,692 (-0.9%)
Average Vehicle Speed (Q) (mph)		42.00	42.30	42.32	51.81	51.84	52.13
Numbers of Vehicles (%)	Passenger Cars	1,694,441 (90.3%)	1,694,654 (90.3%)	1,696,171 (90.4%)	1,506,219 (80.2%)	1,507,339 (80.3%)	1,507,086 (80.3%)
	Light Duty Trucks	60,378 (3.2%)	60,452 (3.2%)	60,442 (3.2%)	55,794 (3.0%)	55,851 (3.0%)	55,790 (3.0%)
	Medium Duty Trucks	27,660 (1.5%)	27,576 (1.5%)	27,601 (1.5%)	25,876 (1.4%)	26,083 (1.4%)	26,111 (1.4%)
	Non-Port Heavy Duty Trucks	35,337 (1.9%)	35,306 (1.9%)	35,474 (1.9%)	33,521 (1.8%)	33,686 (1.8%)	33,764 (1.8%)
	Port Heavy Duty Trucks	59,226 (3.2%)	58,112 (3.1%)	56,884 (3.0%)	56,178 (3.0%)	55,131 (2.9%)	53,567 (2.9%)
	Total	**1,877,041** (100%)	**1,876,100** (100%)	**1,876,572** (100%)	**1,677,587** (100%)	**1,678,089** (100%)	**1,676,318** (100%)
Modal shift impact on port trucks (%) (Total vehicles)		-	**1.61%** (0.05%)	**3.29%** (0.1%)	-	**1.70%** (0.06%)	**3.49%** (0.1%)

TABLE 3 Average Emission Results for All Scenarios (total working hours: 12hours)

Scenario	**Vehicle Type**	**Upper bound (kg)**				**Lower bound (kg)**			
		CO	**HC**	**NO$_X$**	**PM$_{2.5}$**	**CO**	**HC**	**NO$_X$**	**PM$_{2.5}$**
Base Scenario	**LDV**	33,359.7 *(289.1)*	1,630.5 *(11.6)*	3,539.7 *(36.4)*	131.4 *(0.9)*	30,208 *(105.8)*	1,441 *(4.8)*	3,240.9 *(12)*	117.7 *(0.4)*
	LDT	1,752.5 *(37.9)*	81.8 *(1.9)*	241.5 *(5.6)*	7.8 *(0.2)*	1,673.4 *(16.6)*	75.2 *(0.8)*	234.3 *(2.4)*	7.2 *(0.1)*
	MDT	943 *(27.4)*	41.8 *(1.3)*	145.9 *(4.4)*	3.9 *(0.1)*	917.2 *(13.5)*	38.9 *(0.6)*	144.5 *(2.1)*	3.7 *(0.1)*
	HDT	1,632.6 *(63.4)*	140.3 *(11.5)*	1,954.1 *(60.4)*	42.7 *(1.7)*	1,424.1 *(23.9)*	109.3 *(2.8)*	1,907.8 *(30)*	39.7 *(1)*
	Port Truck	2,394.4 *(48)*	199.8 *(9)*	2,958.1 *(50.3)*	64.4 *(1.5)*	2,279.1 *(34.8)*	177.3 *(4.1)*	3,023.4 *(39.4)*	63.6 *(1.2)*
	Total	40,082.2 *(306.6)*	2,094.1 *(23.5)*	8,839.3 *(126.1)*	250.3 *(3.3)*	36,501.8 *(117.5)*	1,841.7 *(7.7)*	8,550.9 *(50.6)*	231.8 *(1.6)*
Scenario 1	**LDV**	33,419 *(299.9)*	1,633.5 *(13.8)*	3,546.7 *(36.3)*	131.7 *(1.1)*	30,244.1 *(114.4)*	1,443.1 *(5.8)*	3,244.6 *(12.7)*	117.8 *(0.5)*
	LDT	1,751.3 *(35.2)*	81.8 *(2)*	241 *(5.1)*	7.8 *(0.2)*	1,676.7 *(13.5)*	75.4 *(0.6)*	234.7 *(1.9)*	7.2 *(0.1)*
	MDT	942 *(27.7)*	41.8 *(1.3)*	145.8 *(4.5)*	3.9 *(0.1)*	924.5 *(20.2)*	39.2 *(0.9)*	145.6 *(3.2)*	3.7 *(0.1)*
	HDT	1,635.4 *(56.6)*	141 *(9)*	1,951.6 *(65.6)*	42.7 *(2)*	1,433.7 *(27)*	110.2 *(2.9)*	1,919.3 *(53.3)*	40.1 *(1.5)*
	Port Truck	2,278.6 *(40.3)*	190.1 *(7.4)*	2,803.7 *(56.5)*	60.8 *(1.7)*	2,168.6 *(26.3)*	169 *(4)*	2,874 *(43.2)*	60.5 *(1.1)*
	Total	40,026.4 *(370.1)*	2,088.2 *(25.2)*	8,688.9 *(146.2)*	246.9 *(4.3)*	36,447.6 *(122.6)*	1,836.9 *(8.7)*	8,418.2 *(73.5)*	229.3 *(1.9)*
Scenario 2	**LDV**	33,397.4 *(287.8)*	1,630.3 *(10.8)*	3,545.9 *(38.9)*	131.5 *(0.9)*	30,214.5 *(124.2)*	1,440.1 *(5)*	3,243.1 *(14.7)*	117.6 *(0.4)*
	LDT	1,748.1 *(37.2)*	81.4 *(1.7)*	241 *(6)*	7.7 *(0.2)*	1,679.1 *(20.9)*	75.5 *(1)*	234.9 *(2.8)*	7.2 *(0.1)*
	MDT	937.7 *(27.8)*	41.4 *(1.3)*	145.3 *(4.6)*	3.9 *(0.1)*	921.9 *(15.1)*	39 *(0.6)*	145.2 *(2.4)*	3.7 *(0.1)*
	HDT	1,629.3 *(57.6)*	139.3 *(11.4)*	1,964.2 *(61.7)*	42.7 *(1.8)*	1,435.2 *(22.2)*	110.5 *(2.6)*	1,923.8 *(33.6)*	40.1 *(1.1)*
	Port Truck	2,174.4 *(48.2)*	181.7 *(10)*	2,672.9 *(50.6)*	58.2 *(1.4)*	2,050.6 *(20.5)*	159.4 *(3.6)*	2,716.2 *(43.4)*	57.1 *(1.4)*
	Total	39,886.9 *(306.8)*	2,074.1 *(25.9)*	8,569.3 *(132.4)*	244 *(3.1)*	36,301.3 *(128.4)*	1,824.5 *(6.7)*	8,263.2 *(64)*	225.8 *(2)*

( ): Standard deviation

TABLE 4 Emission Increases from Rail Operations

Line Haul Characteristics

Segment	**Distance (mile)**	**Speed Limits (mph)**	**Assumed Notch**	**Number of locomotives/train for Baseline**	**Number of trains/day for Baseline**
1	8	25	3	4	48
2	10	40	5	4	48
3	2	25	3	4	48

NO_X*

Segment	**Emission factor (g/hr)**	**Baseline**		**Scenario 1**		**Scenario 2**	
		# of locomotives /day	Emission rates (kg/day)	# of locomotives/ day	Emission rates (kg/day)	# of locomotives/ day	Emission rates (kg/day)
1	7,267	192	446.5	204	474.4	216	502.3
2	25,584	192	1,228.0	204	1,304.8	216	1,381.5
3	7,267	192	111.6	204	118.6	216	125.6
Total	-	-	1,786.1	-	1,897.8	-	2,009.4

$PM_{2.5}$*

Segment	**Emission factor (g/hr)**	**Baseline**		**Scenario 1**		**Scenario 2**	
		# of locomotives /day	Emission rates (kg/day)	# of locomotives/ day	Emission rates (kg/day)	# of locomotives/ day	Emission rates (kg/day)
1	427	192	24.1	204	25.7	216	27.2
2	348	192	15.4	204	16.3	216	17.3
3	427	192	6.1	204	6.4	216	6.8
Total	-	-	45.6	-	48.4	-	51.3

NO_X* (or $PM_{2.5}$*) = travel time × no. of locomotives/train × no. of train/hour × emission factor

TABLE 5 Daily Potential Emission Impacts of Modal Shifts to Rail (unit: kg/day)

		Scenario 1				**Scenario 2**			
		NO_X		**$PM_{2.5}$**		**NO_X**		**$PM_{2.5}$**	
		Upper	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
Modal shift	**Reduced Port truck emissions(1)**	154.4	149.4	3.6	3.1	285.2	307.2	6.2	6.5
	Additional Locomotive emissions(2)	111.7		2.8		223.3		5.7	
	Net Change(3)	**42.7**	**37.7**	**0.8**	**0.3**	**61.9**	**83.9**	**0.5**	**0.8**
Reduced total emissions(4)		150.4	132.7	3.4	2.5	270.0	287.7	6.3	6.0
System-Wide Reduction (%)(5)		0.5%	0.4%	0.3%	0.1%	0.7%	1.0%	0.2%	0.4%

Net Change(3) = Reduced Port truck emissions(1) – Added Locomotive emissions(2)
System-Wide Reduction(5) = (Reduced total emissions(4) – Additional Locomotive emissions(2)) / Baseline total emissions for NO_X (or $PM_{2.5}$) × 100%.

The List of Figures

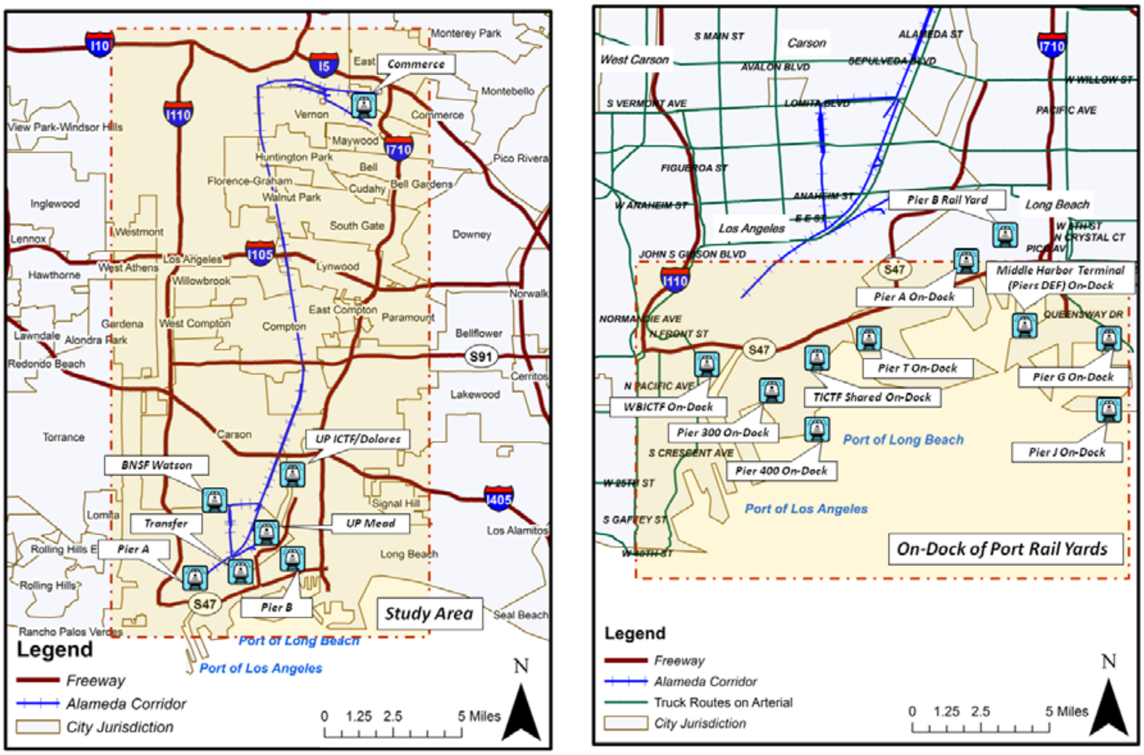

FIGURE 1 Freight corridor (left panel) and on-dock rail yards (right panel) linked to the San Pedro Bay Ports.

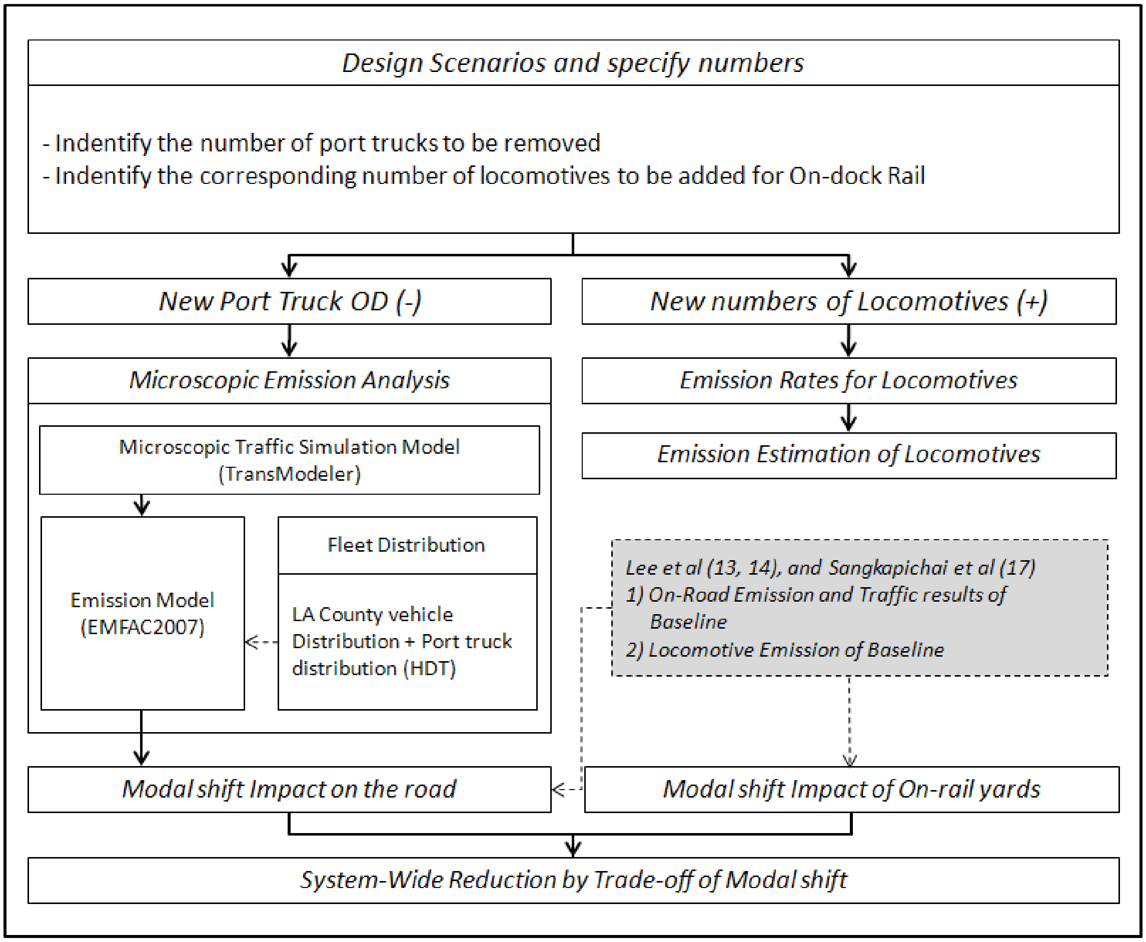

FIGURE 2 Framework of modal shift impact analysis.

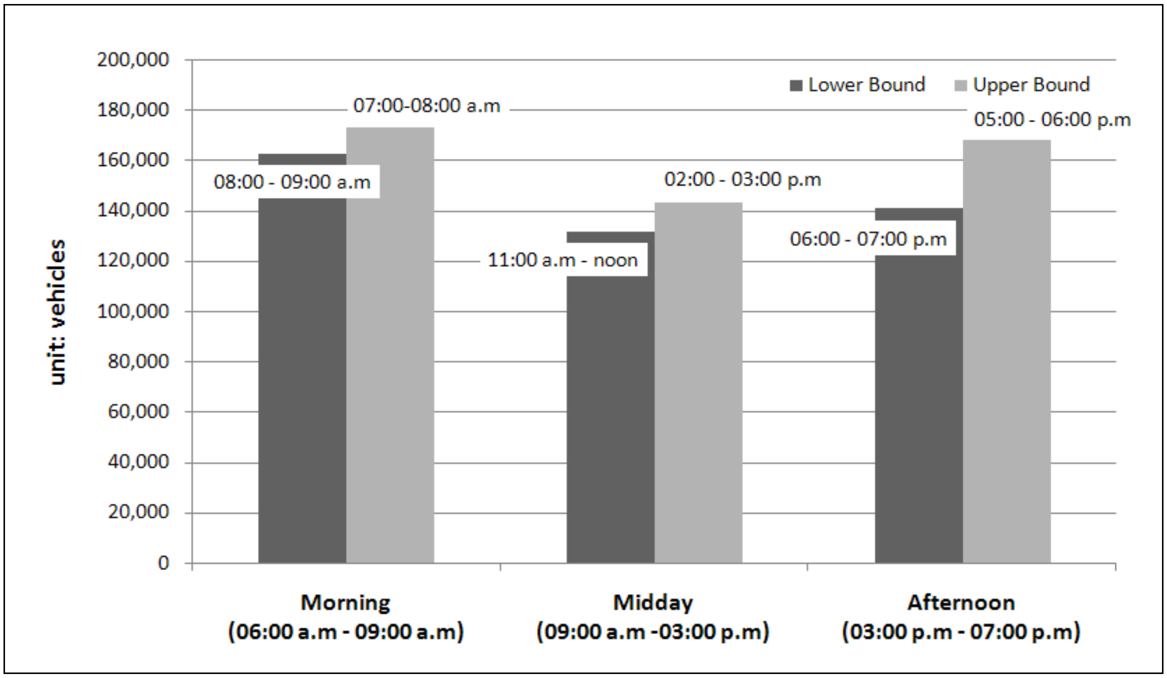

FIGURE 3 Comparison of total traffic volumes for representative hours.

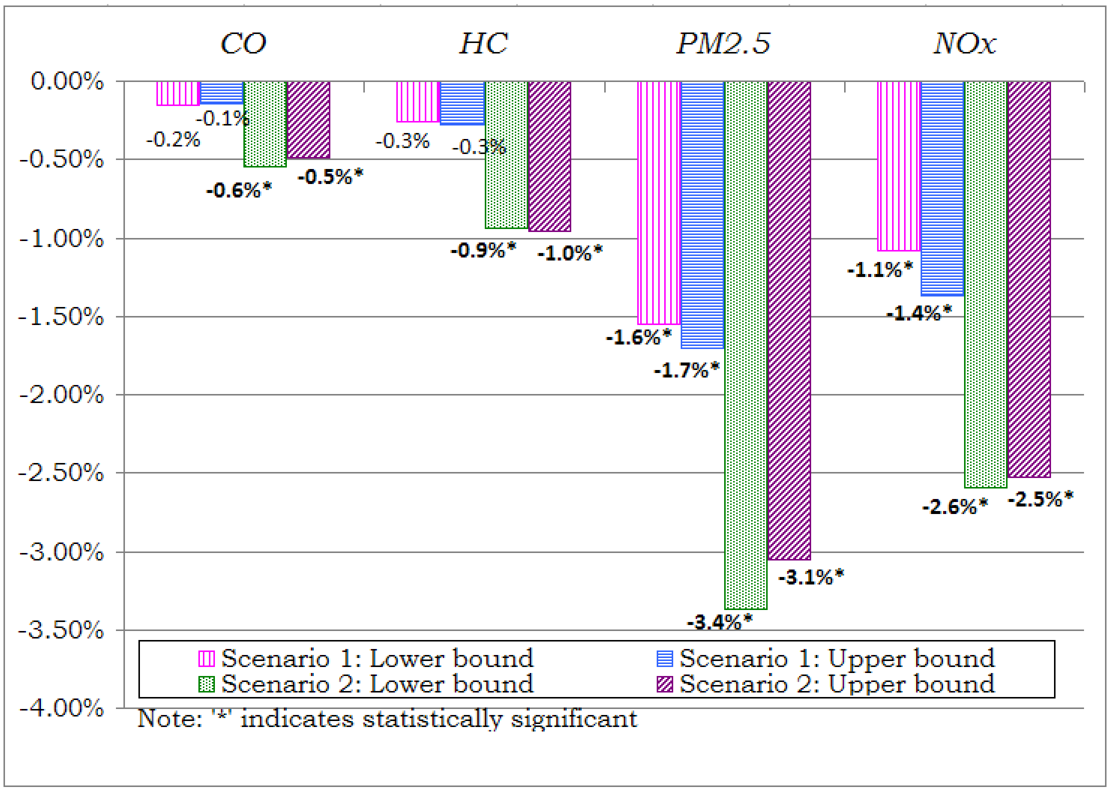

FIGURE 4 (a) Daily percentage changes in pollutants compared to baseline (all vehicles).

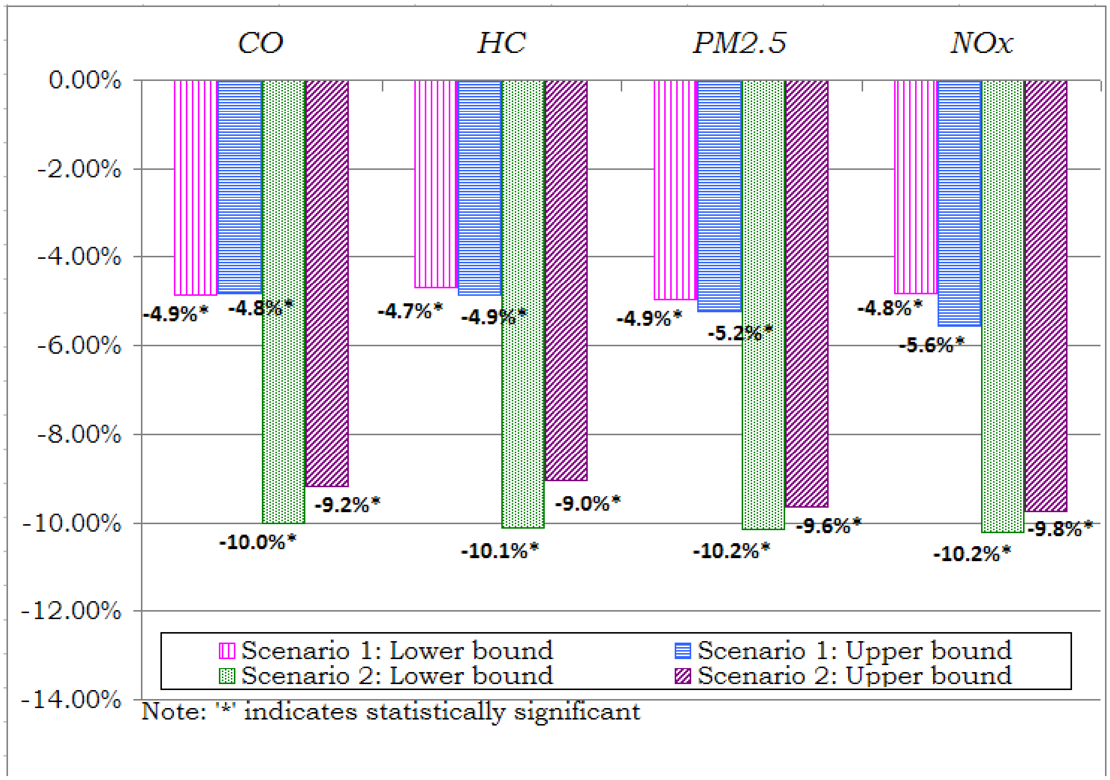

FIGURE 4 (b) Daily percentage changes in pollutants compared to the baseline (Port trucks only).