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Microscopic Simulation and Emissions Study of the Electrification of the I-710 Freight Corridor

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Microscopic Simulation and Emissions Study of the Electrification of the I-710 Freight Corridor

THESIS

submitted in partial satisfaction of the requirement
for the degree of

MASTER OF SCIENCE

in Civil Engineering

by

Sarah Tasnim

Thesis Committee:
Professor Jean-Daniel Saphores, Chair
Professor R. Jayakrishnan
Professor Michael McNally

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Abstract of the Thesis

Microscopic Simulation and Emissions Study of the Electrification of the I-710 Freight Corridor
By
Sarah Tasnim
Master of Science in Civil Engineering
University of California, Irvine 2014
Professor Jean-Daniel Saphores, Chair

Due to heavy congestion and air pollutants emissions from the increase in container trucks traveling on the I-710, Caltrans and Metro have been looking into viable alternatives for solving these problems. The heavy health burden on residents of the areas surrounding the I-710 has been a cause for concern to these agencies for some time. In this study, I rely on microscopic traffic simulation and on operating modes (OpModes) lookup tables from MOVES to estimate changes in congestion and in emissions of various air pollutants (including nitrogen oxides (NO_x) and particulate matter (PM)) resulting from the creation of electrified truck lanes on I-710. This alternative was tested for four scenarios corresponding to different percentage of electrified heavy-duty trucks in the I-710 corridor. My results show that creating electrified lanes would slightly reduce congestion in terms of average overall network speed. I also found a substantial reduction in the emissions of several air pollutants by port-related heavy duty trucks, which ranged from 44% to 94% in the scenarios considered. Overall, the reduction in emission possible by the electrification of the freight corridor is a significant improvement but as proposed, the electrification of the I-710 would also create additional traffic problems. This suggests that planning models (such as TransCad) are not sufficient to properly evaluate preliminary designs of freeway changes.

Chapter 1 Introduction

1.1 Background

The Long Beach Freeway (I-710) Corridor Improvement Project is being proposed by the following agencies and funding sources: Caltrans, Los Angeles (LA) County Metro, Gateway Cities Council of Governments (GCCOG), Southern California Agency of Governments (SCAG), the Ports of Los Angeles and Long Beach (aka the San Pedro Bay Ports, or SPBP), and the I-5 Joint Powers Authority (I-5 JPA). The project on the I-710 is located in LA County between Ocean Boulevard and the SR-60 (see Figure 1). The selected baseline year is 2005.

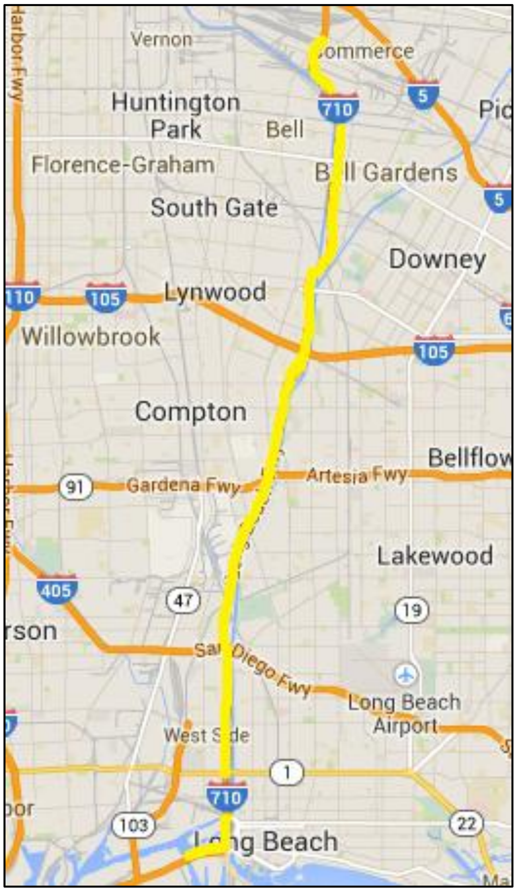

Figure 1. Study Area

The study area used by Caltrans and Metro for this project includes the flow of goods from the SPBP complex at the southern end of the I-710 up to the BNSF & Union Pacific (UP) railroad yards in the cities of Vernon and Commerce. The whole project encompasses about 18 miles. The main reasons that motivate this project include elevated air emissions, increased traffic congestion (partly due to projected increases in truck volumes), high accident rates, and the need to modernize the I-710.

Of particular concern is the impact on local residents of the high levels of diesel particulate matter (PM) emitted by freeway traffic. A URS study found that during 2005, the highest estimated cancer risks (1,200 out of 1 million people affected) happened near the I-710, the Ports, and the rail yards (URS pg. 27). Because of high levels of PM_{10} and $PM_{2.5}$, this area is a non-attainment area for small micro-airborne particulate matter. Health impacts from PM exposure include reduced lung functions, asthma, and heart problems. Toxic air exposure studies by the South Coast Air Quality Management District (SCAQMD) show that diesel particulate matter (DPM) produced by diesel trucks is the highest contributor to cancer risks caused by air pollution in this study area (Caltrans pg. 2).

Another cause for concern is the high level of traffic congestion on the I-710 where many stretches experience a level of service (LOS) of E or F throughout the day. Freight trucks that serve the Ports are heavy contributors to congestion and to SCAG’s projected traffic increase on the I-710. SCAG’s 2012 Regional Transportation Plan forecasts that container truck volume could increase from 14 million annual TEUs (twenty-foot equivalent units) in 2008 to 43 million annual TEUs in 2035. Moreover, high accident rates along the corridor can be attributed to congestion, poor freeway design, and high traffic volumes. The percentage of accidents involving trucks is higher on the I-710 than the state average (Caltrans pg. 3). Lastly, updating and modernizing the I-710 is necessary because it was designed and constructed in the 1950s before large increases in freight traffic.

The purpose of the I-710 Major Corridor Study (MCS), completed in 2005, was to find possible solutions to the above problems. Among the options examined, which included a no build alternative, it considered a design with ten general purpose lanes that includes four separated freight-truck-only lanes. This is alternative 6B which is also known as the I-710 widening and modernization plus separated truck freight corridor for use only by zero-emission vehicles. The freight corridor for that alternative extends from the northern portion of Ocean Boulevard at the I-710 to the BNSF rail yards on Bandini Blvd (Caltrans pg. 12). Under this alternative, zero-emission trucks using the corridor would be powered by electric engines instead of conventional internal combustion engines. Viable options for trucks with zero tailpipe emissions include linear induction motors, linear synchronous motors, or electric motors. To circumvent weaknesses in battery technology, overhead catenary wires could be installed to supply trucks with electric power while traveling along the corridor. Trucks would also have automated control systems, which would be computer controlled for steering, braking, and accelerating. This would allow trucks to travel in platoons, thereby increasing the corridor's capacity.

SCAQMD chose the German engineering and electronics group Siemens to build an "eHighway" near the Ports for testing purposes (Seiple, 2014). Overhead catenary wires will be installed along the two-way mile long road. Alameda Street's north- and south-bound sections at the intersection of Sepulveda Blvd will be a Siemens demonstration site. Trucks used for testing will have an advanced electricity utilization system so they can connect or disconnect from the overhead catenary wires at any speed. Siemens will be working with the Volvo group for developing this innovative system. The first truck to be tested after the infrastructure is constructed will be in July 2015 (Seiple, 2014). Figure 2 shows an electric hybrid truck developed by Siemens that uses overhead catenary wires on a test on an eHighway in Germany (Reh, 2014).

Figure 2. Siemens Electric Truck on eHighway (Reh 2014)

1.2 Objective

In this context, the purpose of this study is to use microscopic simulation software (TransModeler 3.0) coupled with the OpMode approach in MOVES to assess whether (and by how much) the addition of the eHighway lanes in both directions of the I-710 would relieve congestion and decrease the emissions of various air pollutants in the corridor.

Chapter 2 Literature Review

This chapter summarizes relevant papers that rely on output from microscopic traffic simulation models to estimate emissions. I also review papers that studied the I-710 or surrounding locations in order to find solutions to congestion and air emissions problems.

In an early study, Ahn (1998) used microscopic traffic simulation models in order to estimate emissions based on fuel consumption and look-up tables for different vehicle accelerations and speeds. The pollutants tested were hydrocarbons, carbon monoxide, and nitrogen oxide for eight light duty vehicles with the data collected by the Oak Ridge National Laboratory in 1997 (Ahn 1998). The eight vehicles utilized an internal combustion engine and ranged from 1988 to 1995 model vehicles.

In 2007, Yang and Regan studied general truck management strategies (GTMS) with micro simulation traffic models created in TransCAD and Paramics (Yang & Regan 2007). Their study area consisted of a portion of the I-710 corridor selected for its high truck volume. They focused on restricting a variable number of lanes on the freeway to only heavy-duty freight trucks. Of the three scenarios tested (based on the number of restricted lanes), the one that provided the most overall benefits was when two lanes in each direction are dedicated to freight trucks. Benefits included reductions in braking, accelerating, and passing of other vehicles by freight trucks.

You et *al.* (2009) used microscopic simulation to estimate traffic emissions on the I-110 and I-710 freeways (You 2009). They used TransModeler for their microscopic traffic simulator and OD estimation adjusted with PeMS data (You et *al.*, 2009). EMFAC2007 emission factors with vehicle trajectories from the TransModeler simulation model were combined to estimate emissions. Microscopic emissions models were not used because they did not have appropriate emission factors for newer trucks and did not allow estimating PM emissions for heavy-duty trucks.

An environmental study of the I-710 and the San Pedro Bay Ports complex was performed by Lee *et al.* (2009), using vehicle trajectories from a microscopic simulation model combined with an emissions model (Lee 2009). The scenarios considered include a baseline case based on 2005 data for a morning peak hour, replacing a fraction of existing diesel trucks with clean trucks, reducing the volume of trucks either by shifting containers from trucks to trains or by rerouting trucks away from the I-710.

In a related study, Lee *et al.* (2010) relied on microscopic simulation and emissions estimation modeling with CALPUFF and BenMAP to study the aggregated health impacts from nitrogen oxide (NO_x) and particulate matter (PM) exposure near the I-710 and the I-110 (Lee 2010). They found that these costs exceed $200 million per year and that heavy duty trucks contribute over 90% of these pollutants, with one third by port trucks.

Most recently, air pollution resulting from truck operations was studied by Cho and Hu (2013) who used truck flow estimates, developed a network model for simulations, and used the EMFAC air pollution emissions model (Cho 2013). Data were gathered from IMPLAN (Impacts for Planning) and FAF (Freight Analysis Framework) for the MSAs (Metropolitan Study Area) they studied. They tested three scenarios including replacing old trucks with newer trucks (similar to the Clean Truck Program), improving the network by adding zero-emission truck only lanes on the I-710 (50% of existing truck flows were redirected to these lanes), and implementing an intermodal port that would promote railways at seaports to reduce truck flows from the Ports by 50%. They found that vehicle replacement strategies help reduce overall air pollution emissions in larger areas. Additionally, they reported that zero emission truck lanes strategies can decrease air pollution emissions in specific areas around highway segments. Lastly, they found that reducing air pollution in a specific location can increase emissions in zones outside of that location.

Finally, Bhagat (2014) studied the impact of shifting of port-related drayage trucks from peak hours to off-peak hours as part of the PierPASS program adopted by the ports of Los Angeles and Long Beach. His research utilized microscopic traffic simulation and emissions estimation through the use of the OpMode lookup table approach. Dynamic OD estimation was used in the traffic simulation with data gathered from the PeMS database and Caltrans’ AADT data (Bhagat 2014). Bhagat studied the effect on congestion, pollution, and pollution-related health impacts from the PierPASS program. My work builds on his models.

Chapter 3 Data and Methodology

3.1 TransModeler Network Alterations

To understand proposed network changes for alternative 6B (which I analyze in this thesis), I first went through Metro's Draft Environmental Impact Report (EIR) and determined which of the alternatives for the I-710 project was suitable for analyzing congestion and emissions impacts. I then implemented proposed changes under alternative 6B on a large microscopic traffic simulation in TransModeler 3.0 that was built by Bhagat (2014). Two lanes in the north and south-bound directions were added to the I-710 for the proposed freight corridor as described in the EIR. Lanes were added along the centerline of the freeway (where HOV lanes typically are located) in each direction. Also, the lane additions began at the Ports and ended at Bandini Ave where rail yards are located. The existing geometry of the roads was not altered but the roads were shifted according to accommodate additional lanes.

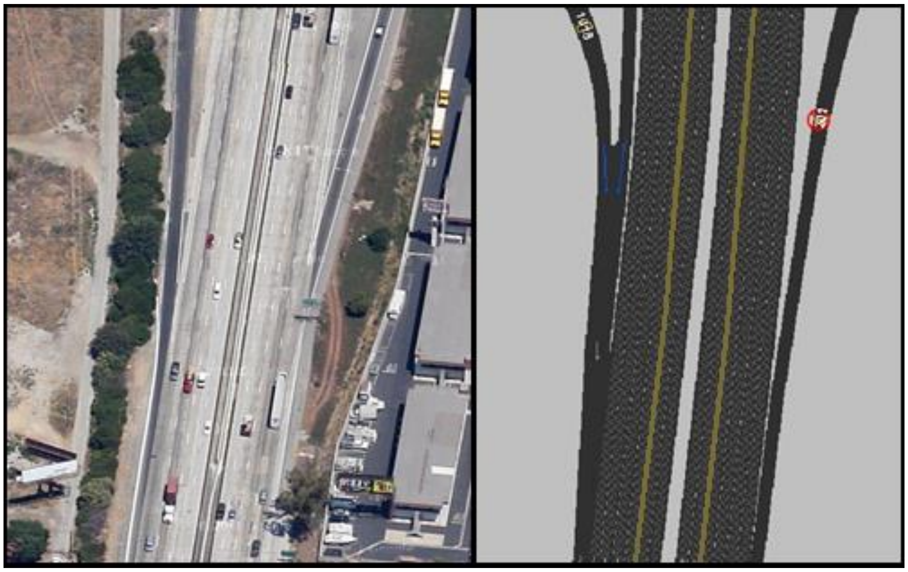

Figure 3. Freight Corridor Addition to the I-710 (at Firestone Blvd.)

Figure 3 shows a satellite image of the northbound off-ramp and southbound on-ramp at Firestone Boulevard on the I-710 (on the left) next to the TransModeler version showing the freight corridor addition (on the right).

The lane attributes for the two lane additions were set to “User A” reserved and “User B” prohibited. “User A” was defined as zero-emission port trucks only while “User B” referred to all other types of vehicles. All other lanes in the mainline had their attributes set to “User B” reserved and “User A” prohibited to keep electric freight trucks in their dedicated lanes. Additionally, a barrier was created to separate electrified freight corridor lanes from the other lanes and to prevent “User B” vehicles from entering and using those lanes.

The Concept Plans included within Metro’s Draft EIR where checked to see which on- and off-ramp locations would be permitted for use by these electric port trucks, in addition to the Ports origin ramps. Barriers were removed at these locations to allow the trucks to use the ramps at those specific locations only. These ramps were located at: Anaheim St., Del Amo Blvd., Artesia Blvd., I-105 freeway interchange, Firestone Blvd., Atlantic Blvd., and Washington Blvd (Caltrans Appendix O).

3.2 Electric Port Trucks OD Estimation and Data Collection

For the simulation, a travel demand model derived from SCAG data with a TransCAD sub-area analysis was combined with previously estimated OD matrices (Lee *et al.*, 2012; Bhagat, 2014). Seed OD demands were created by applying the proportion method as inputs for a traffic simulation in order to gather detector and path data. Path-based dynamic OD estimation was applied to the traffic simulation data (Choi *et al.*, 2009).

Freeway traffic count data were collected from the PeMS database and AADT data from Caltrans. In total, data from 354 mainline freeway, ramp, and arterial detectors were used for the simulation. Count data were compared to the path-based dynamic OD estimation to see if the GEH statistics converged (Bhagat 2014). If convergence was achieved, the path-based OD estimation was used. Otherwise, the updated OD matrices were put back into the traffic simulator and the process was repeated until convergence is achieved (Bhagat 2014).

Dynamic OD demands were used because traffic patterns can better be portrayed this way, especially during peak periods throughout the day when congestion is present. Five minute count data were aggregated into 15 minute count data for a simulation lasting 24 hours, which therefore gave 96 demand files for all vehicle types for my simulations. With four main vehicle types plus variations within those types, seven vehicle types were used in the simulation as listed in Table 2:

Table 1. Vehicle Types

Vehicle Type	Vehicles included	Variations
LDV = light duty vehicle	PC = Passenger cars	*PC* for general purpose lanes and *PC* for HOV lanes
LDT = light duty truck	PU = pickup trucks, vans, and SUVs	
MDT = medium duty truck	ST = single-unit truck	
HDT = heavy duty truck	TT = tractor trailer	*TT* for general purpose lanes, *TT* for port-related trips, *TT* for port trips via freight corridor

A Matlab program was used to create the electric port trucks OD estimation matrices. Estimated OD trips for port truck trips were split into four scenarios: 80% and 20%, 67% and 33%, 50% and 50%, and 100% and 0%. The first percentage pertains to electric port trips and the second to conventional (non-electric) port trips. Only trips that either originate or end at the ports or at the ramps specified in the Concept Plans were affected by this shift.

The demand files were converted into TransModeler matrices. Matrices were altered to reflect the different vehicle types used in my simulation. “User A” was used only for electric port trucks for the corridor, and “User B” was used for all other vehicles. In order to distinguish the different vehicles from the trip trajectories in the emissions analysis later on, the other matrix attributes had to be altered as well. “Probe” was selected for distinguishing all trucks and “ETC” was selected for distinguishing all port trucks. In addition, HOV (high occupancy vehicle) was selected only for HOV passenger cars.

Table 2. TransModeler Matrix Settings

Vehicle Class	Vehicle Type	Field in Matrix	HOV	ETC	User A	User B	Probe
Passenger Cars	PC1	3	N	N	N	Y	N
Passenger Cars	PC1	4	Y	N	N	Y	N
Light Duty Truck	PU	5	N	N	N	Y	Y
Medium Duty Truck	ST	6	N	N	N	Y	Y
Heavy Duty Truck (non-port related)	TT	7	N	N	N	Y	Y
Heavy Duty Truck (port related)	TT	8	N	Y	N	Y	Y
Heavy Duty Truck (electric port related)	TT	9	N	Y	Y	N	Y

3.3 Emissions Estimation

To understand the exposure of people living near the I-710 to toxic pollutants generated by local traffic, I estimated emissions of various air pollutants to quantify overall air emissions changes from adding lanes for electric trucks only on the I-710.

3.2.1 Types of Pollutants

The pollutants considered include gaseous hydrocarbons (HC measured in kg), carbon monoxide (CO measured in tons), nitrogen oxide (NO_x measured in kg), atmospheric carbon dioxide (CO_2 measured in tons), carbon dioxide equivalent (CDE measured in tons), and particulate matter (PM_{10} and $PM_{2.5}$ measured in kg). Carbon dioxide equivalent is an equivalent measure of carbon dioxide that would have the same global warming effect as other greenhouse gases or mixtures of greenhouse gases (Manitoba Eco Network). The following provide a brief description of these pollutants and of their health impacts:

1. *Hydrocarbons (HC)*: This type of emission is caused by fuel only partially burning during engine processes. Smog's major component, ground-level ozone, is created from the combination of hydrocarbons, nitrogen oxides, and sunlight. Serious respiratory issues, lung damage, and eye irritation result from exposure to hydrocarbons. Exhaust hydrocarbon may also cause cancer (U.S. E.P.A. 1994).
2. *Carbon Monoxide (CO)*: CO is and odorless and colorless gas that results mainly from incomplete mobile engine combustion processes. Negative impacts include a reduction in the flow of oxygen to the blood and to vital organs, such as the brain and the heart. Continuous exposure to large levels of CO increases the mortality rate of people exposed, particularly if they have heart disease (U.S. E.P.A. 2012).

3. *Nitrogen Oxide (NO_x)*: The high temperature and pressure involved in engine combustion processes cause nitrogen and oxygen particles in the air to form nitrogen oxides. Combined with hydrocarbons and sunlight, this leads to increased levels of ozone. Exposure to NO_x can cause airway inflammation and worsening asthma symptoms (U.S. E.P.A. 1994).
4. *Atmospheric Carbon Dioxide (CO_2)*: Unlike hydrocarbon and carbon monoxide, carbon dioxide results from the complete burning of fuel molecules during the combustion process. Although direct negative health effects have not been linked to carbon dioxide, it is a powerful greenhouse gas that contributes to global climate change (U.S. E.P.A. 1994).
5. *Particulate Matter (PM)*: Particulate matter is a complex mixture of small particles (dust, soils, and metals), liquid chemical droplets, and sulfate and nitrate acids. Due to their very small size, PM particles have the ability to go deep into lungs and directly into the bloodstream. Impacts include irregular heartbeat, increased asthma symptoms, breathing problems, increased deaths in people with lung and heart disease, and increased heart attacks (U.S. E.P.A. 2012).

3.2.2 Estimation Procedure

Because my study network is large, estimating emissions using EPA's MOVES software would be very time consuming. I relied instead on the OpMode lookup table approach proposed by Claggett (2011) and implemented by Lee (2010 and Bhagat (2014).

Before applying this procedure to my data, I created a new vehicle class to represent zero-emission drayage trucks that use the eHighway in the freight corridor. A vehicle class file is created from the trips generated by the simulation used in a Monte Carlo simulation code written in Matlab (Bhagat, 2014). This code was altered to include an additional vehicle class for electric port trucks so they could be identified during the estimation of emissions. Using a vehicle ID and type, a new vehicle category was assigned to each TransModeler vehicle type that is then assigned to the OpMode vehicle ID (see Table 3 below).

Table 3. Vehicle Category by Type

Vehicle Type	Vehicle Category	OpMode Vehicle ID
PC	11	1 2
LDT	24	3 4 5 6
MDT	25	7 8
HDT (non-port)	26	9 10 11 12 13 14 15 16
HDT (port)	46	17
HDT (electric port)	86	18

These vehicle categories were then mapped to a new vehicle class through uniform fleet distributions in Los Angeles County. These distributions came from 2005 EMFAC's vehicle class and age distributions. These distributions were then mapped to be recognized as MOVES vehicles using either gas or diesel as a fuel source.

Table 4. L.A. County Mapped Vehicle Class Fleet Distribution

Vehicle Class	Vehicle Type in EMFAC		Vehicle Type in MOVES		Fuel Type	Fleet Distribution
LDV	1	Passenger Cars	21	Passenger Cars	Gas	99.54%
					Diesel	0.46%
LDT	2	Light-Duty Trucks 1	31	Passenger Trucks	Gas	23.16%
					Diesel	0.72%
	3	Light-Duty Trucks 2	32	Light Commercial Trucks	Gas	75.93%
					Diesel	0.19%
MDT	4	Medium-Duty Trucks	51	Refuse Trucks	Gas	99.57%
					Diesel	0.43%
HDT	5	Light-Heavy-Duty Trucks 1	52	Single Unit Short haul Trucks	Gas	39.94%
					Diesel	4.84%
	6	Light-Heavy-Duty Trucks 2	53	Single Unit Long-haul Trucks	Gas	8.61%
					Diesel	5.36%
	7	Medium-Heavy-Duty Trucks	61	Combination Short-haul Trucks	Gas	7.11%
					Diesel	20.92%
	8	Heavy-Heavy-Duty Trucks	62	Combination Long-haul Trucks	Gas	1.55%
					Diesel	11.67%

Second-by-second trajectories from TransModeler simulations were split by time and operating mode (OpMode) vehicle type ID for each link in the entire network. The benefit of using second-by-second trajectories is that congestion effects (acceleration, braking, idling) can better be modeled. Vehicle categories from the Monte Carlo simulation were needed for the trajectory split. OpMode lookup tables for different vehicle classes and pollutants were created based on vehicle age distribution (mapped from vehicle type in EMFAC to MOVES), temperature, and humidity. This method was suggested by Claggett (2011) to efficiently estimate vehicular emissions.

Table 5. OpMode Vehicle Type ID and TransModeler Vehicle Type Mapping

Vehicle Type in MOVES		Fuel Type	OpMode Look-up Table Vehicle Type ID	TransModeler Vehicle Type
21	Passenger Cars	Gas	1	LDV
		Diesel	2	
31	Passenger Trucks	Gas	3	LDT
		Diesel	4	
32	Light Commercial Trucks	Gas	5	
		Diesel	6	
51	Refuse Trucks	Gas	7	MDT
		Diesel	8	
52	Single Unit Short haul Trucks	Gas	9	HDT (Non-Port related)
		Diesel	10	
53	Single Unit Long-haul Trucks	Gas	11	
		Diesel	12	
61	Combination Short-haul Trucks	Gas	13	
		Diesel	14	
62	Combination Long-haul Trucks	Gas	15*	
		Diesel	16	
62	Combination Long-haul Trucks	Diesel	17	HDT (Port)
62	Combination Long-haul Trucks	Diesel	18	HDT (Port-related via freight corridor)

Another Matlab program was used to process the trajectory split output and the OpMode lookup tables to estimate the emissions produced during the simulation by vehicle class and time for all of the vehicles present in each simulation. The data were first separated by vehicle classes (1 through 18 as per the OpMode vehicle ID), and then by time of day before aggregating emissions over 24 hours. After this, vehicle classes were separated and aggregated into five vehicle types (LDV, LDT, MDT, HDT, and Ports) used for analysis by another Matlab program. Emissions were also categorized and separated by the road type, either arterial or freeway, for the various vehicles simulated.

Chapter 4 Results

4.1 Traffic Performance Results

To assess TransModeler simulations, I collected a number of summary statistics, including the number of vehicles that traveling within the network by vehicle class as well as vehicle miles travelled (VMT, in miles), vehicle hours travelled (VHT, in hours), and average speed traveled by vehicles in their vehicle class (mph).

Tables 6 to 9 present summary statistics for each vehicle class before and after the electrification of the freight corridor. Table 6 presents the baseline case (before electrification). Table 7 shows statistics after electrification for an 80%-20% split (i.e., 80% of port trucks are assumed to be electrified and 20% are not).

Table 6. Traffic Performance Measures before Electrification

Vehicle Class	Vehicle Count	VMT (mi)	VHT (hr.)	Average Speed (mph)
LDV	3,554,497	19,021,643	854,264	43.82
LDT	50,202	315,792	10,460	30.19
MDT	39,635	223,617	8,729	25.62
HDT	48,938	309,785	11,817	26.22
Port HDT	55,881	604,620	12,105	49.95
All vehicles	3,749,153	20,475,456	897,375	35.16

Over 93% of all of vehicles in the microscopic traffic simulation consisted of light-duty vehicles, including those traveling in HOV lanes, and 7% were trucks. Approximately 30% of all trucks were drayage trucks serving the ports. The average speed for port heavy-duty trucks was approximately 50 mph and the average speed traveled by all vehicles in the network is 35.2 mph.

Table 7. Traffic Performance Measures after Electrification (80%-20% split)

Vehicle Class	Vehicle Count	VMT (mi)	VHT (hr.)	Average Speed (mph)
LDV	3,555,079	19,072,565	883,575	42.17
LDT	50,240	325,009	11,159	29.13
MDT	39,653	225,620	9,098	24.80
HDT	49,028	316,426	12,018	26.33
Conventional Port HDT	10,765	205,879	3,362	36.73
Electric Port HDT	45,171	428,584	13,333	61.31
All vehicles	3,749,936	20,574,084	932,545	36.74

After electrification (Table 7), the total number of non-port truck vehicles changed very little but port trucks are now split between conventional and electric vehicles. The average speed of all vehicles traveling in the network increased to 36.7 mph as compared to 35.2 mph before electrification. In particular, we note that electrified port trucks have an average speed of 61.3 mph (an increase of over 20%), which is the highest among all vehicle classes simulated. As expected, electrified trucks would benefit from having a dedicated corridor on the freeways where they can reach higher speeds as they do not have to sit through traffic congestion.

Table 8. Comparison of Total Vehicle Count and VMT and Average Speed

	ΔVehicle Count	ΔVMT (mi)	ΔQ (mph)
Difference	783	98,628	1.59

A comparison between Tables 6 and 7 (see Table 8) shows only a small change in simulated vehicles (783 vehicles or 0.02% of the total) and 98,628 (0.48%) more miles traveled throughout the network. This difference is due to queuing at a few heavily-traveled arterials and to inefficient re-routing of some vehicles that could not follow their intended path due to traffic interferences. Also, the overall average vehicular speed increase of 1.6 mph on the network shows an improvement and a reduction in congestion. The main cause for this improvement is the substantial increase in the capacity of the I-710. However, not all vehicles benefitted from this increase in speed. Looking at both tables 6 and 7, the following vehicle classes had a slight reduction in average speed: LDV, LDT, and MDT. A possible reason for this is explored in Subsection 4.3 “Network Problems.”

Table 9 shows a comparison of the electric port HDT count, the average speed traveled by all vehicles in the network in miles per hour, and the change in average speed traveled by all vehicles compared to the average speed from the base case (or 35.16 mph) for the different scenarios tested. The scenarios considered include (the first percentage is directed to the freight corridor trips and the remaining percentage is for all other port-related trips: 67% and 33%, 80% and 20%, and 100% and 0%.

The increasing number of electric port HDT counts with each tested scenario is consistent with the increasing percentage of electrification of port trucks with each scenario. As Table 9 shows, the average speed of all vehicles in the simulation increases with the electrification of the corridor in every tested scenario. This shows that if at least or more than fifty percent of the existing drayage trucks are converted and shifted to the freight corridor, there will be a slight reduction in congestion. However, accident data was not used in the simulation which may affect these results.

Table 9. Overall Vehicle Count, VMT, and Average Speed for All Scenarios

Scenario	Electric Port HDT Count	Average Speed (mph)	Δ Average Speed (mph)
50%, 50%	27,398	37.23	2.07
67%, 33%	36,899	37.27	2.11
80%, 20%	45,171	36.74	1.58
100%, 0%	55,548	37.38	2.22

4.2 Emissions Estimation Results

Tables 10 to 12 show the amounts of HC, CO, NO_x, CO_2, CDE, PM_{10}, and $PM_{2.5}$ produced from 24-hour traffic simulations by vehicle class and by road type. For my thesis, I was especially interested in port-related truck emission. Table 10 shows emissions estimation before the freight corridor is electrified (the baseline case.)

Table 10. Before Freight Corridor Emissions Estimation

Vehicle Category and Road Type	**HC (kg)**	**CO (tons)**	**NO_x (kg)**	**CO_2 (tons)**	**CDE (tons)**	**PM_{10} (kg)**	**$PM_{2.5}$ (kg)**
LDV arterial	1091.6	33.5	3119.5	1328.6	1339.3	280.7	258.4
LDV freeway	3339.6	100.5	14507.3	5565.9	5594.7	487.2	448.7
LDT arterial	17.6	0.7	57.3	20.1	20.3	3.1	2.9
LDT freeway	72.6	2.5	405.1	123.0	123.8	9.1	8.4
MDT arterial	4.4	0.2	17.4	3.9	3.9	0.4	0.4
MDT freeway	11.6	0.6	79.5	15.8	15.9	1.1	1.0
HDT arterial	30.8	0.6	573.4	50.1	50.1	34.7	33.6
HDT freeway	146.3	2.9	3624.7	289.4	289.8	143.3	138.7
Ports arterial	39.2	0.4	1897.4	138.7	138.8	128.9	125.0
Ports freeway	466.5	3.1	20223.8	1352.6	1352.9	783.1	759.6
All	5220.4	145.0	44505.4	8888.2	8929.4	1871.5	1776.7

Before the freight corridor is added to the I-710, port HDT trucks contributed approximately 10% to total hydrocarbon emissions produced by the network (see Table 10). Port HDT trucks also were responsible for nearly 2% of carbon monoxide, 50% of nitrogen oxide, 17% of atmospheric carbon dioxide, 17% of carbon dioxide equivalent, 50% of PM_{10}, and 50% of $PM_{2.5}$. Hence, port HDT trucks alone contributed half of all traffic emissions of NO_x, PM_{10}, and $PM_{2.5}$ in my study area.

Table 11. After Freight Corridor Emissions Estimation

Vehicle Category and Road Type	HC (kg)	CO (tons)	NO_x (kg)	CO_2 (tons)	CDE (tons)	PM_{10} (kg)	$PM_{2.5}$ (kg)
LDV arterial	1095.9	33.6	3129.5	1333.4	1344.2	281.6	259.3
LDV freeway	3569.7	105.8	14921.9	5800.1	5832.1	534.2	491.9
LDT arterial	18.0	0.7	58.6	20.5	20.7	3.2	3.0
LDT freeway	86.5	2.8	432.9	135.2	136.1	10.6	9.7
MDT arterial	4.5	0.2	18.0	4.0	4.0	0.4	0.4
MDT freeway	14.1	0.7	84.6	17.3	17.3	1.1	1.1
HDT arterial	31.5	0.6	581.2	50.7	50.8	35.1	34.0
HDT freeway	163.6	3.2	3899.2	314.0	314.4	160.0	154.9
Ports arterial	9.2	0.1	445.3	33.2	33.0	30.5	29.3
Ports freeway	120.7	0.8	5211.7	342.6	344.8	201.1	195.1
All	5113.8	148.4	28782.9	8051.1	8097.5	1257.7	1178.7

Table 11 shows estimated emissions for the 80% and 20% scenario: After the addition of the electrified lanes, port HDT trucks contributed to almost 3% of total hydrocarbon emissions, 0.6% of total carbon monoxide emissions, 20% of total nitrogen oxide emissions, 5% of total atmospheric carbon dioxide emissions, 5% of total carbon dioxide equivalent emissions, 18% of total PM_{10} emissions, and 19% of total $PM_{2.5}$ emissions. As expected, the overall contribution of port HDT trucks to the emissions produced in the simulation decreased due to the conversion of 80% of the existing drayage trucks to zero-emission trucks.

Table 12. Percent Differences in Emissions (80%, 20% split)

Vehicle Category and Road Type	ΔHC (%)	ΔCO (%)	ΔNO_x (%)	ΔCO_2 (%)	ΔCDE (%)	ΔPM_{10} (%)	$\Delta PM_{2.5}$ (%)
LDV arterial	0.39	0.34	0.32	0.36	0.36	0.34	0.34
LDV freeway	6.89	5.22	2.86	4.21	4.24	6.64	6.64
LDT arterial	1.83	2.42	2.16	1.99	1.98	2.28	2.28
LDT freeway	19.13	13.51	6.86	9.87	9.96	16.13	16.12
MDT arterial	1.97	1.80	3.43	2.45	2.45	3.02	3.13
MDT freeway	20.04	9.87	6.51	9.08	9.10	7.35	7.29
HDT arterial	2.08	2.01	1.36	1.38	1.38	1.08	1.08
HDT freeway	11.84	9.30	7.57	8.49	8.50	11.66	11.69
Ports arterial	-76.45	-76.12	-76.53	-76.04	-76.23	-76.37	-76.55
Ports freeway	-74.12	-74.01	-74.23	-74.67	-74.51	-74.32	-74.32
All	-2.04	2.39	-35.33	-9.42	-9.32	-32.80	-33.66

Table12 shows the percentage differences in emissions after the freight corridor is electrified compared to the baseline. It shows that the percentage of all pollutants produced by port HDT trucks decreased roughly by 76% on arterials and by 74% decrease on freeways for this particular scenario. For nitrogen oxide and particulate matter emissions, the percentage reduction by port HDT trucks is very important as nearly 50% of those emissions in the network were coming just from these vehicles. There was a 33% decrease in these emissions in the network.

However, we can also note increases in emissions for some vehicle classes. For LDTs, MDTs, and HDTs traveling on freeways, emissions increased are clearly not due to the difference in vehicle count compared to the simulation before electrification. This discrepancy is explained in Subsection 4.3 “Network Problems.”

Figures 4 and 5 show a comparison of nitrogen oxide emissions from the trucks traveling on port-related trips on the arterials and freeways in the 80%, 20% split scenario: Emissions of NO_x (in kg) are shown for 15 minute periods (totaling 24 hours) on both road types. As can be seen, the highest emissions occur during the peak period of midday to early afternoon as there is congestion and higher volume of traffic at that time. There was a significant reduction in emissions of nitrogen oxide with the electrification of the freight corridor as can be seen above. Because most of the trucks traveling for port-related trips were traveling on the freeway, that graph is smoother than the one for the arterials. Also, the nitrogen oxide emissions were nearly ten times higher on freeways than on arterials during most parts of the day. The following figures 6 and 7 are for the PM_{10} pollutant emitted by port trucks comparison.

Figures 6 and 7 also show the emissions on both road types and compare before and after the electrification of the freight corridor. As with the nitrogen oxide emissions, PM_{10} emissions from heavy duty trucks decreased greatly. Emissions began to increase around 3 AM and then were highest between 8 AM and 4 PM. Then emissions decreased back until midnight. We note that particulate matter emissions were five times higher on freeways than on arterials.

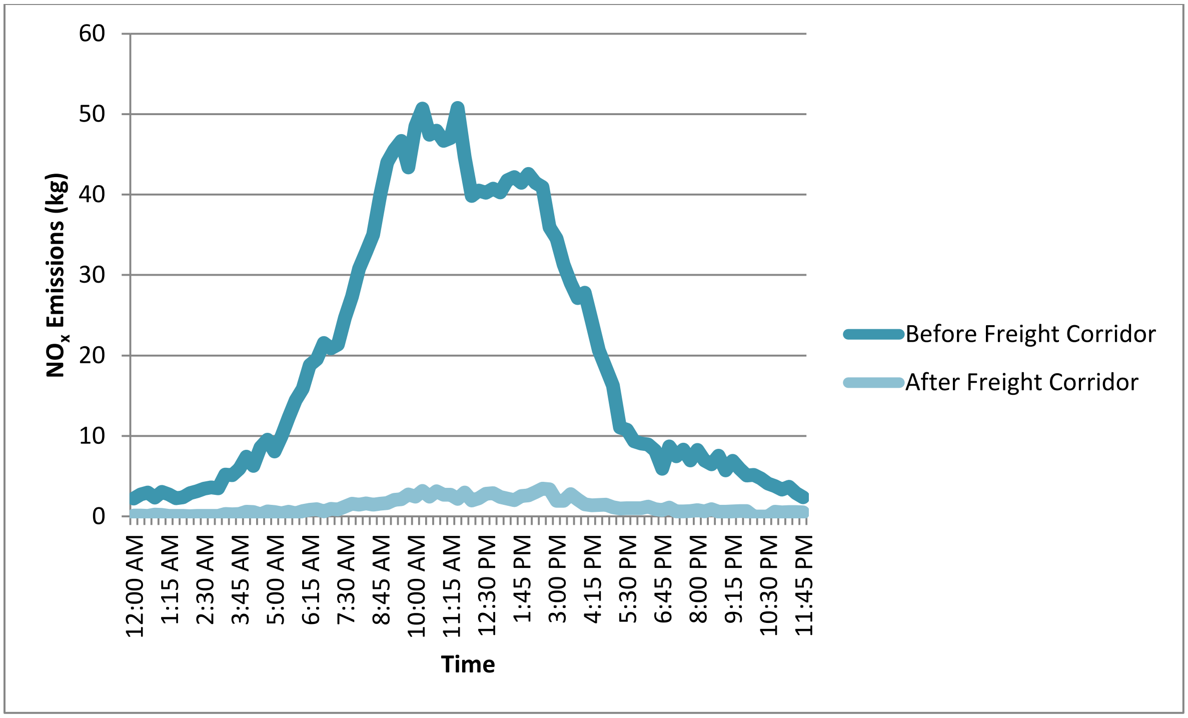

Figure 4. NO_x Emissions for Port Trucks on Arterials Comparison

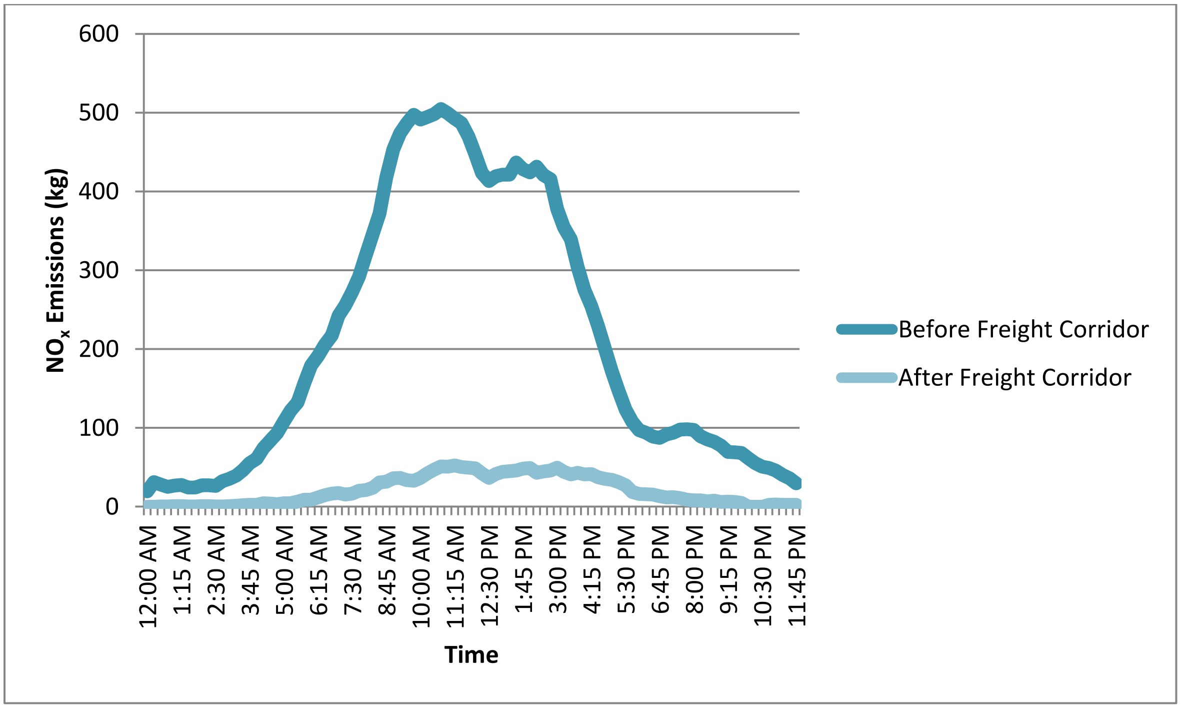

Figure 5. NO_x Emissions for Port Trucks on Freeways Comparison

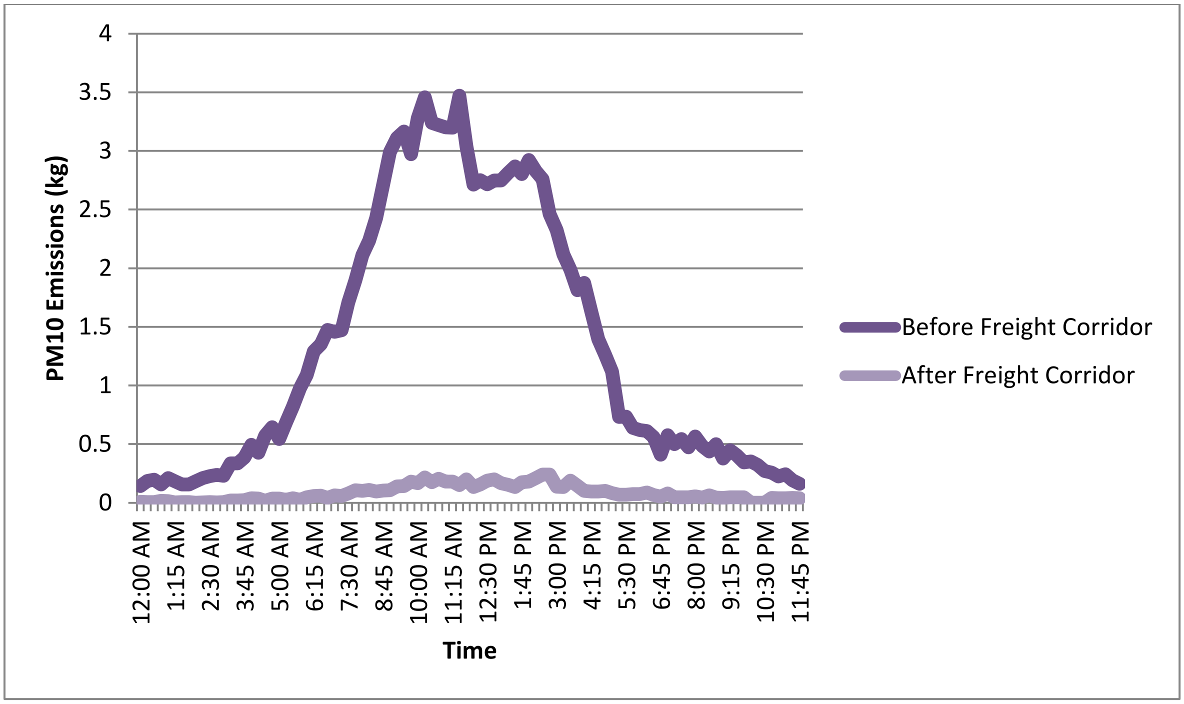

Figure 6. PM$_{10}$ Emissions for Port Trucks on Arterials Comparison

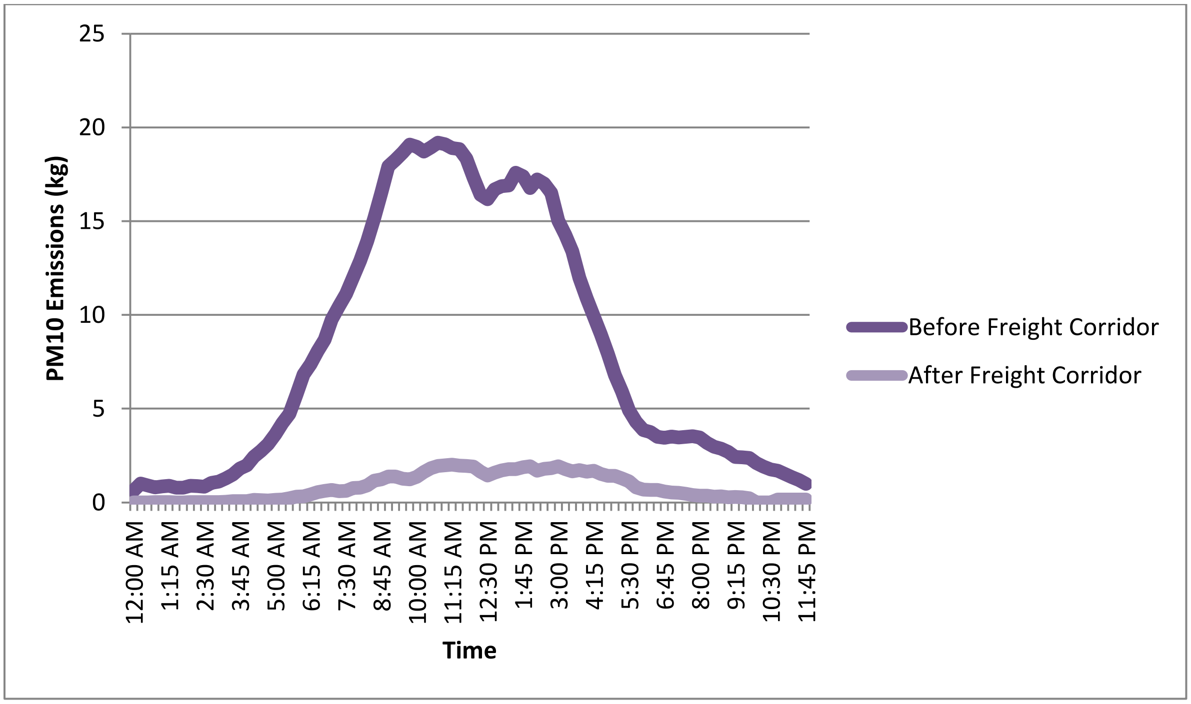

Figure 7. PM$_{10}$ Emissions for Port Trucks on Freeways Comparison

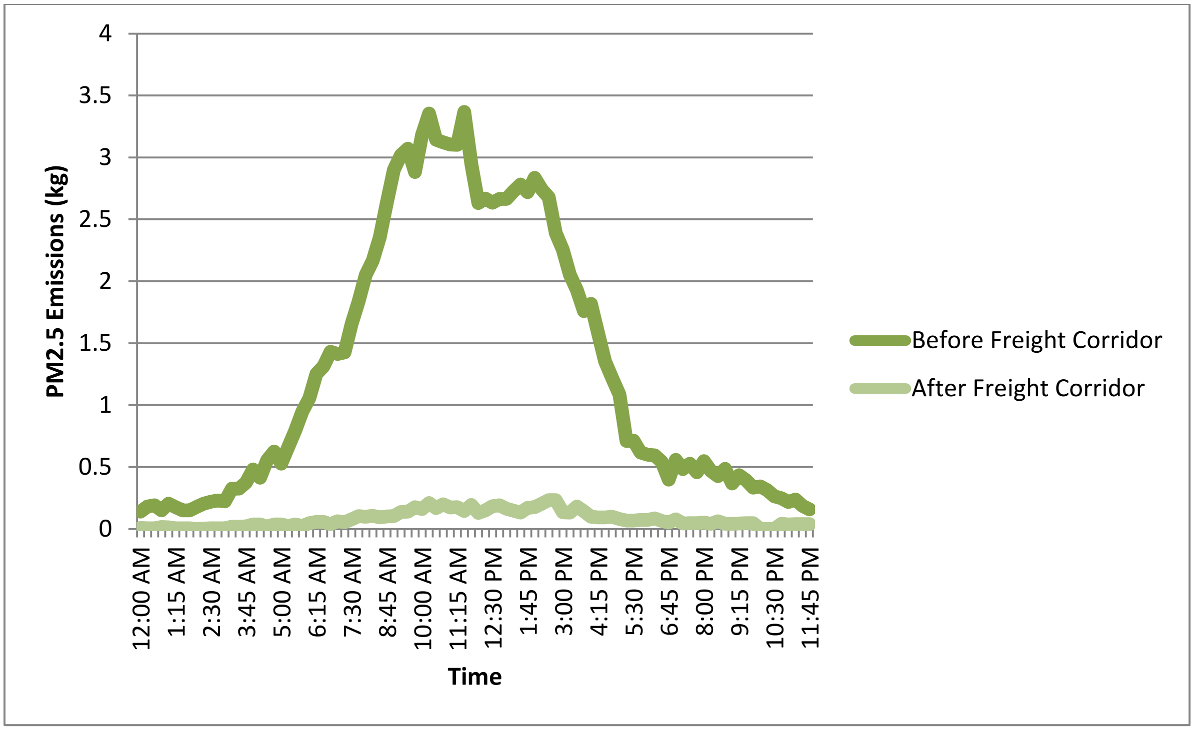

Figure 8. PM$_{2.5}$ Emissions for Port Trucks on Arterials Comparison

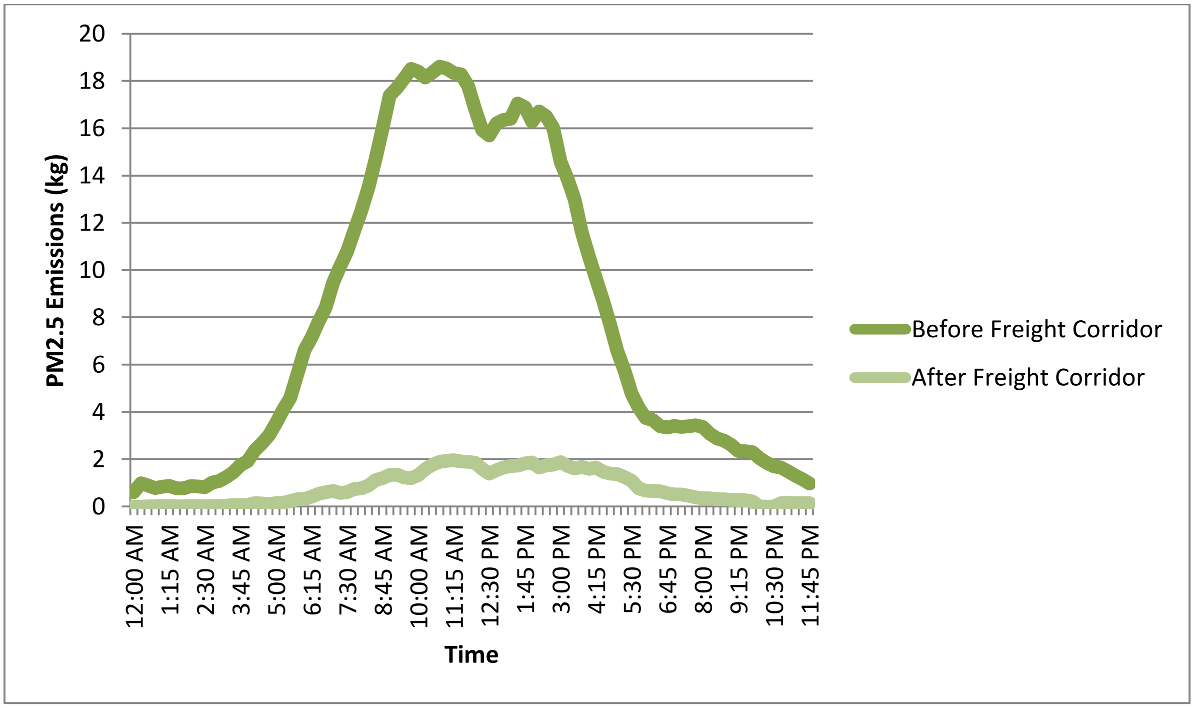

Figure 9. PM$_{2.5}$ Emissions for Port Trucks on Freeways Comparison

Figures 8 and 9 show the same trend of decreasing $PM_{2.5}$ emissions from heavy-duty port trucks after the freight corridor is electrified. Again, $PM_{2.5}$ emissions were five times higher on freeways than on arterials. Nitrogen oxide and particulate matter are heavy-duty truck pollutants that are of most concerns. These graphs show that the emissions of these pollutants can be greatly reduced if the freight corridor is electrified with existing trucks being fully or partially converted to zero-emission vehicles.

Table 13. Percent Differences in Emissions (50%, 50% split)

Vehicle Category and Road Type	ΔHC (%)	ΔCO (%)	ΔNO_x (%)	ΔCO_2 (%)	ΔCDE (%)	ΔPM_{10} (%)	$\Delta PM_{2.5}$ (%)
LDV arterial	0.39	0.34	0.32	0.36	0.36	0.34	0.34
LDV freeway	6.89	5.22	2.86	4.21	4.24	6.64	6.64
LDT arterial	2.31	2.48	2.47	2.43	2.43	2.41	2.41
LDT freeway	16.88	12.18	6.20	8.79	8.87	14.69	14.68
MDT arterial	2.31	2.26	2.12	2.18	2.19	1.02	0.99
MDT freeway	18.53	9.25	6.39	8.54	8.56	7.80	7.76
HDT arterial	0.67	0.81	-0.12	0.04	0.04	-0.10	-0.11
HDT freeway	9.80	8.56	6.16	7.01	7.01	9.33	9.34
Ports arterial	-47.95	-47.04	-47.33	-47.66	-47.95	-47.76	-47.27
Ports freeway	-44.35	-44.02	-44.66	-44.36	-44.64	-44.53	-44.82
All	0.78	3.08	-20.72	-4.40	-4.39	-18.46	-19.09

Tables 13 and 14 show the percentage differences in emissions for the seven pollutants considered for the other scenarios considered. The rest of the scenarios consist of the following splits of the existing heavy duty trucks to zero-emission trucks (the first percentage is for the zero-emission vehicle and the second percentage is for what remains of the existing trucks): 50% and 50%, 67% and 33%, and 100% and 0%. Difference were calculated with respect to the baseline (emissions data collected before the freight corridor was electrified.)

Table 14. Percent Differences in Emissions (67%, 33% split)

Vehicle Category and Road Type	ΔHC (%)	ΔCO (%)	ΔNO_x (%)	ΔCO_2 (%)	ΔCDE (%)	ΔPM_{10} (%)	$\Delta PM_{2.5}$ (%)
LDV arterial	0.39	0.34	0.32	0.36	0.36	0.34	0.34
LDV freeway	6.89	5.22	2.86	4.21	4.24	6.64	6.64
LDT arterial	1.83	2.42	2.16	1.99	1.98	2.28	2.28
LDT freeway	19.13	13.51	6.86	9.87	9.96	16.13	16.12
MDT arterial	1.97	1.80	3.43	2.45	2.45	3.02	3.13
MDT freeway	21.04	9.87	6.51	9.08	9.10	7.35	7.29
HDT arterial	2.08	2.01	1.36	1.38	1.38	1.08	1.08
HDT freeway	11.84	9.30	7.57	8.49	8.50	11.66	11.69
Ports arterial	-65.35	-65.47	-65.22	-65.89	-65.52	-65.05	-65.33
Ports freeway	-61.44	-61.67	-61.36	-61.59	-61.23	-61.77	-61.81
All	-0.99	2.59	-29.17	-7.37	-7.24	-27.00	-27.76

Table 13 shows the percentage change in emissions when half of the existing heavy-duty trucks traveling on port-related trips are converted to zero-emission vehicles to drive on the freight corridor. It shows a 44% to 47% reduction in all pollutants emitted by heavy-duty port trucks traveling on freeways and arterials, respectively. For nitrogen oxide and particulate matter, there was an overall network percentage reduction of approximately 19%. This is a substantial improvement over the baseline case.

Table 15. Percent Differences in Emissions (100%, 0% split)

Vehicle Category and Road Type	ΔHC (%)	ΔCO (%)	ΔNO_x (%)	ΔCO_2 (%)	ΔCDE (%)	ΔPM_{10} (%)	$\Delta PM_{2.5}$ (%)
LDV arterial	0.39	0.34	0.32	0.36	0.36	0.34	0.34
LDV freeway	6.89	5.22	2.86	4.21	4.24	6.64	6.64
LDT arterial	1.80	2.29	2.35	2.13	2.13	2.31	2.31
LDT freeway	19.41	13.58	7.09	10.08	10.17	16.66	16.66
MDT arterial	1.22	1.39	1.06	0.47	0.48	1.54	1.68
MDT freeway	19.13	8.87	6.68	8.57	8.59	11.02	11.04
HDT arterial	1.19	0.40	0.93	0.87	0.87	0.89	0.89
HDT freeway	10.22	8.47	6.66	7.35	7.35	10.34	10.37
Ports arterial	-96.80	-96.79	-96.88	-96.87	-96.87	-96.91	-96.91
Ports freeway	-94.35	-94.01	-94.12	-94.08	-94.08	-94.10	-94.10
All	-4.10	1.86	-45.37	-12.77	-12.67	-42.69	-43.76

Table 14 shows emissions results when two-thirds of the existing port drayage trucks are converted into zero-emission vehicles. It shows an additional 20% reduction in the seven pollutants emitted by port trucks as compared to the 50%-50% scenario. For other pollutants except carbon monoxide, there were also reductions in emissions over the network.

As expected, the largest percentage reduction in emissions was obtained with the conversion of all existing drayage trucks to electric hybrid trucks (only for drayage trucks using the I-710) as shown in Table 15. In that case, the percentage reduction in all seven pollutants for port trucks traveling on freeways was around 94%. In addition, all pollutants emitted by heavy-duty port trucks traveling on arterials decreased by 97%. The overall network reduction in nitrogen oxide and particulate matter emissions was approximately 44%, which is quite substantial.

However, to gauge the effectiveness of this approach, it would be necessary to have an idea of the costs of implementing this measure (infrastructure plus vehicles); these data are currently not available.

4.3 Network Problems

As indicated in Subsections 4.1 and 4.2, some discrepancies in these results require some explanation. Although there was an increase in overall network speed after electrification of the freight corridor, it did not apply to all vehicle classes. Moreover, emissions of some pollutants changed more than proportionately on freeways by some vehicle classes. Let us explain these apparent inconsistencies.

First, Tables 16 and 17 show statistics for the vehicle classes that have increased emissions on freeways before and after electrification. I also calculated the average vehicle miles traveled and average vehicle hours traveled by vehicle class.

Table 16. Traffic Performance Measures before Electrification

Vehicle Class	Vehicle Count	VMT (mi)	VHT (hr.)	Average VMT per vehicle (mi)	Average VHT per vehicle (hr.)
LDV	3,554,497	19,021,643	854,264	5.35	0.24
LDT	50,202	315,792	10,460	6.29	0.21
MDT	39,635	223,617	8,729	5.64	0.22
HDT	48,938	309,785	11,817	6.33	0.24

Table 17. Traffic Performance Measures after Electrification (80%-20% split)

Vehicle Class	Vehicle Count	VMT (mi)	VHT (hr.)	Average VMT per vehicle (mi)	Average VHT per vehicle (hr.)
LDV	3,555,079	19,072,565	883,575	5.36	0.25
LDT	50,240	325,009	11,159	6.47	0.22
MDT	39,653	225,620	9,098	5.69	0.23
HDT	49,028	316,426	12,018	6.45	0.25

A comparison of average VMT and VHT per vehicle class before and after electrification in Tables 16 and 17 shows relatively small differences, with only small increases after electrification compared to before: there were 582 more LDVs, 38 more LDTs, 18 more MDTs, and 90 more HDTs recorded in the "after-electrification" simulation.

Table 18. Percent Differences in Emissions (80%, 20% split)

Vehicle Category and Road Type	ΔHC (%)	ΔCO (%)	ΔNO_x (%)	ΔCO_2 (%)	ΔCDE (%)	ΔPM_{10} (%)	$\Delta PM_{2.5}$ (%)
LDV arterial	0.39	0.34	0.32	0.36	0.36	0.34	0.34
LDV freeway	6.89	5.22	2.86	4.21	4.24	6.64	6.64
LDT arterial	1.83	2.42	2.16	1.99	1.98	2.28	2.28
LDT freeway	19.13	13.51	6.86	9.87	9.96	16.13	16.12
MDT arterial	1.97	1.80	3.43	2.45	2.45	3.02	3.13
MDT freeway	20.04	9.87	6.51	9.08	9.10	7.35	7.29
HDT arterial	2.08	2.01	1.36	1.38	1.38	1.08	1.08
HDT freeway	11.84	9.30	7.57	8.49	8.50	11.66	11.69
Ports arterial	-76.45	-76.12	-76.53	-76.04	-76.23	-76.37	-76.55
Ports freeway	-74.12	-74.01	-74.23	-74.67	-74.51	-74.32	-74.32
All	-2.04	2.39	-35.33	-9.42	-9.32	-32.80	-33.66

Table 18 shows the percentage difference in pollutants before and after electrification (for the 80%-20% scenario) to detect odd increases in the emission of some pollutants. These increases occurred more on freeways than on arterials, and it affected mostly LDT, MDT, and HDT as the number of LDVs is much larger. Moreover, statistics show that vehicles traveled slightly more after electrification than before. To find an explanation, I audited the trips file created by TransModeler after each simulation. It showed that some trips between two seemingly close points required traveling many more miles than necessary (and also taking much longer). This problem affected approximately 800 vehicles out of 3,749,153 simulated vehicles. Moreover, a similar problem existed for the baseline TransModeler network (before the electrification) for approximately 300 vehicles. One possible explanation is that some parameters in models underlying TransModeler may need to be changed to prevent this behavior.

Attempts to track vehicles with this odd behavior proved fruitless because the number of vehicles affected is quite small compared to the total. Moreover, there does not appear to be a simple way of comparing trip files between two simulations as vehicle IDs change from one simulation to another.

Given the large number of passenger vehicles in my simulations, they were not affected by this problem. Moreover, there were (by construction) no extra emissions for electrified drayage trucks. However, for LDTs, MDTs, and HDTs, the much larger mileages of some vehicles affected emissions results as explained above.

Additional investigations revealed that some vehicles were rerouted because they were unable to follow their intended paths due to interference from other vehicles, partly due to the design of the new lanes on the I-710. More specifically, one reason for this problem is the barrier created in the network by the electrified lanes; this barrier is only removed in small areas to allow electrified trucks to use ramps specified in the concept plans. These plans state that electrified trucks can only use the following ramps: Anaheim St., Del Amo Blvd., Artesia Blvd., I-105 freeway interchange, Firestone Blvd., Atlantic Blvd., and Washington Blvd (Caltrans Appendix O). One apparent problem is that the proposed design did not give electric trucks enough space for changing lanes to take these ramps. Another problem is that electric trucks trying to take these ramps cut-off traffic and prevent other vehicles to proceed, which creates additional (unintended congestion). Figure 10 shows the south-bound ramps at Anaheim St. on the I-710 where this problem was evident.

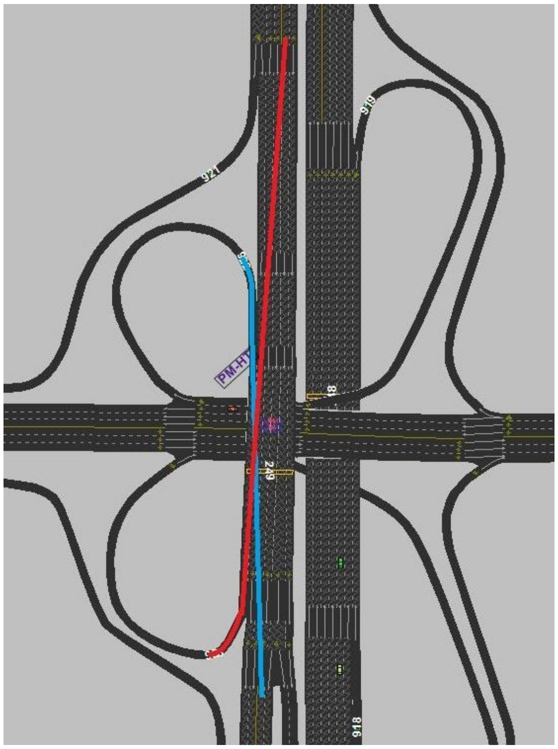

Figure 10. Anaheim St. On and Off Ramps on the I-710

The red route in Figure 10 shows the lane change path that an electrified truck would have to take to get from the electrified lanes to the off ramp at Anaheim St. The blue path shows the lane change trajectory from the on-ramp at Anaheim St. to the electrified lanes that electrified truck entering the I-710 would have to take. The total distance for the red lane path change is about 1150 feet over which a truck needs to cross four lanes. Assuming that the time needed to change lanes from the leftmost lane to the rightmost is 3.7 seconds (Finnegan pg. 15) for a truck traveling at 50 mph, the minimum total distance required would be 1085 feet. Similar calculation show that the distance allowed to cross three lanes for the blue path is barely adequate at 50 mph and insufficient at higher speeds.

These design flaws resulted in traffic disruptions, which I observed during additional simulations. Electrified trucks would cause vehicles to completely stop when they were trying to change lanes, possibly causing some vehicles to change routes. At a minimum, the actual design of electrified lanes should provide more distance for safe lane changing but the inherent safety of this design is questionable. A better alternative would be to create overpasses to allow electrified trucks to leave the I-710 without interfering with the rest of the traffic, which could greatly increase the cost of this alternative. These findings also suggest that traffic planning software may not be adequate for examining freeway design changes as they will ignore potentially design dangerous flaws.

Chapter 5 Conclusions

The purpose of this thesis was to quantify changes in traffic congestion and emissions effects from constructing dedicated lanes for hybrid-electric heavy-duty trucks on the I-710 freeway, a freeway that carries a much larger number of heavy duty trucks than intended when it was designed, over 60 years ago. Four scenarios were tested where different fractions of heavy-duty port trucks were converted to zero-emission vehicles, assuming data for a “representative day” in 2005 I relied on microscopic traffic simulation combined with OpMode lookup tables based on MOVES to obtain state-of-the art traffic simulations and estimates of emissions for various air pollutants..

My results showed a slight increase in overall average network speed, which indicated (as expected) that congestion was reduced after building electrified lanes in this important freight corridor. Reduction in emissions of various pollutants was driven by drayage trucks, which benefited from much improved speeds from the proposed project. However, emissions from other vehicle classes increased because of design flaws in the connections between the electrified truck lanes and various ramps, and possibly because some parameters in underlying simulation models were not optimally set. These problems could not have been detected by the application of transportation planning models, which are commonly used to explore preliminary design, which may result in this context in selecting an alternative that would require much additional work to become acceptable.

Future work could explore ways of adapting the proposed design to improve its performance. It may also be of interest to explore the potential impact from latent demand that may appear when the capacity of the I-710 is increased. In order to better quantify the social costs associated with freight transportation, it would also be of interest to analyze the potential health impacts of various alternatives to retrofit the I-710 using the same approach as Lee *et al.* (2010) and Bhagat (2014). Finally, it would be of interest to study the impact of traffic accident on the proposed alternatives to renovate the I-710.

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