

Network-Based Simulation of Air Pollution Emissions Associated with Truck Operations

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Estimating greenhouse gases (GHGs) and other emissions (especially diesel particulates) is an increasingly important basis for regional policy analysis. According to the EPA (2010a), the transportation sector contributed 27.2% of total GHG emissions in 2008, and 50% of these were from truck operations. This research focuses on estimating GHGs and other emissions (e.g., PM) from freight movements on roads in California as well as the concurrent effects of various mitigation scenarios. The study demonstrates that interregional freight flow data, along with FAF data can be important data sources for emission models. The results are useful not only for estimating GHGs and other emissions based on estimated freight flows, but also for evaluating area-specific environmental impacts of policy alternatives. The analysis shows that emissions impacts vary by study area as well as by policy. A policy alternative that has a significant impact in a specific area may have a trivial impact in a broader region. Also, an emissions reduction in one area may be because of emissions increases in another area. Therefore, it is important to simulate possible emissions impacts by applying a spatially disaggregated model to help decision makers weigh alternatives. The study can also be applied for analyzing environmental justice when the emission results are disaggregated into small areas.

INTRODUCTION

Motivation

Evaluating a regional transportation plan (RTP) in terms of air quality impacts is now essential for local, state, and federal governments. This is why the U.S. Environmental Protection Agency (EPA) has developed the Motor Vehicle Emission Simulator (MOVES), which is an emissions model at the national and sub-regional levels. The California Air Resources Board (CARB) has developed the Emission Factors (EMFAC) model, which is an emissions model for California. The Center for Environment Research and Technology at the University of California, Riverside, has also developed a Comprehensive Modal Emission Model (CMEM) with sponsorship from the National Cooperative Highway Research Program (NCHRP) and the U.S. EPA.

There are many difficulties associated with developing an emissions model. Useable data are scarce and reliable parameters are hard to judge. Basically, emissions levels are estimated by production of emission factors (e.g., tons per vehicle mile by various speeds) and by vehicle activities (CARB 2007, EPA 2010b). Therefore, researchers have worked on estimating reasonable emissions factor parameters, vehicle activities, or interaction between emissions levels and vehicle activities (Barth and Boriboonsomsin 2009). The EMFAC models have incorporated such research results and have been widely used by government agencies and researchers. The EMFAC model may calculate incorrect emission estimates for a small region such as a traffic analysis zone (TAZ) (Barth 1996), but it is useful for identifying trends of emissions levels for large areas such as counties.

Although EMFAC provides comprehensive data, the key factor, vehicle miles traveled (VMT), are not provided as origin-destination flows, leaving opportunities for policy analysis based on transportation network performance limited. The shortcomings may be resolved by using freight flows that are estimated between specific origin-destination pairs by industry sectors. Therefore,

It is expected that consistent sub-state VMT estimates determined via simulation of actual trade flows and consequent use of the road networks would make emissions models much more useful for policy analysis.

Research Objectives

The primary research objective is to simulate air pollution emissions on California road networks associated with truck operations. There are three main procedures of the study. First, truck freight flows are estimated between ZIP code areas. Estimating spatially disaggregated freight flows is essential for this study and ZIP code areas are the most disaggregated spatial units for estimating freight flows by industry sectors. Second, a highway network model is developed to estimate VMT on the network based on the estimated truck origin-destination (O-D) flows. Third, the results from the transportation model are used as inputs to an air pollution emissions model. Various policy scenarios are tested by the developed model.

LITERATURE AND EXISTING MODEL REVIEW

Air pollution emissions caused by transport activities can be grouped into two types: greenhouse gasses (GHGs) and other pollutants. GHGs include Carbon Dioxide (CO₂), Methane (CH₄), and Nitrous Oxide (N₂O) from fuel combustion and F-gases (fluorinated gases) from vehicle air conditioning (Kahn Ribeiro et al. 2007). Other pollutants are Total Gaseous Hydrocarbons (TOG), Carbon Monoxide (CO), Oxides of Nitrogen (NO_x), Particulate matter (PM₁₀, PM_{2.5}), and Oxides of sulfur (SO_x) (CARB 2007; EPA 2010b). Efforts have been made to estimate GHGs and other pollutants caused by transport activities (Benjamin and Long 1995, Cicero-Fernandez and Long 1995). Estimation processes reflect an understanding of which factors affect emissions rates.

In the 1990s, there were several ways to estimate vehicle emission parameters. Equipment such as data-logger or global positioning systems (GPS) were installed to collect data from vehicle operations (Benjamin and Long 1995, Magbuhat and Long 1996). Data were assembled to determine distributions of VMT, trips, temperature, and speed during weekdays and weekends. Grades and other loads effects on emissions were analyzed (Cicero-Fernandez and Long 1995, 1996). Benefits of emission rates data from on-board diagnostics and inspection/maintenance (I/M) were studied (Patel and Carlock 1995). Based on these research results, the California Air Resources Board (CARB) developed an air pollution emissions model called Emission Factors (EMFAC). As mentioned above, VMT provided by EMFAC, a primary input for the model, has limitations for policy analysis. Building a truck O-D matrix is a way to overcome the limitation.

Early studies of truck O-D estimation generally resemble passenger O-D estimation and follow the same methodologies. Gravity models were applied by Meyburg (1976), Swan Wooster (1979), Southworth (1982), Ashtakala and Murthy (1988), and Tamin and Willumsen (1988). Mathematical programming models were applied by Gedeon et al. (1993) and List and Turnquist (1994). Heuristic solution techniques were applied in Tavasszy et al. (1994) and Al-Battaineh and Kaysi (2005). However, it has been widely accepted that freight modeling differs from its passenger counterpart (Holguin-Veras et al. 2001, Wisetjindawat et al. 2006, Hunt and Stefan 2007, Giuliano et al. 2010). Therefore, various approaches have been applied to reflect the unique nature of truck O-D flows.

Truck O-D estimation methodologies can be classified via various criteria. A criterion can be the data involved, which classifies the existing research into two major groups: direct sampling and estimation from secondary data sources (i.e., O-D synthesis) (Cascetta 1984). Direct sampling employs survey data obtained from home interviews, license plate surveys, and roadside surveys to set the parameters of classical sampling theory estimators. The main drawbacks of such techniques are threefold: (1) the variances and covariances of the O-D values depend on the sampling technique and the estimator adopted, and thus may be unstable; (2) bias is often introduced in the parameters

due to lack of calibration and systematic errors in survey work; (3) large-scale traffic surveys tend to be time-consuming and labor-intensive, which can be exacerbated by the dynamic nature of transportation demand. In the case of freight modeling, there is also the problem of data reliability because firms may be reluctant to report various operational details.

Estimation from secondary data sources is an effort to derive the desired O-D matrix by matching the cells with observed or available secondary data conforming to predefined rules. Inputs like link volumes (traffic counts) contain the most important information about O-D distributions and can be updated readily when dynamics are taken into account (Réos et al. 2002). This enables such estimation methods to bypass the need for large surveys and, as a result, they appear attractive. Secondary freight flow data generally have three problems: (1) different data sources reveal different aspects of freight flows, but hardly any single source can describe the complete flows regarding an area; (2) they are not equally available for various modes; (3) most are at an aggregate level, whereas the desired analysis requires more disaggregate data.

Giuliano et al. (2010) attempted to address the first two shortcomings of secondary data sources. Their underlying logic estimates regional commodity-specific O-D matrices by integrating international, interregional, and intraregional trip attractions and productions. The authors generated intraregional productions and attractions utilizing a regional input-output transactions table as well as small area employment data.

The Federal Highway Administration (FHWA) attempted to address these three issues in the Freight Analysis Framework (FAF) database. FAF contains 123 domestic regions and eight foreign regions for exports and imports. Forty-three commodity flows transported by trucks and other modes are provided. FAF is constructed based on the Commodity Flow Survey (CFS). For industrial sectors that CFS does not include, alternative data were used to complete the estimation. Those alternative data include Census of Agriculture for farm-based agricultural shipments, fisheries of the United States for fishery shipments, and U.S. National Input-Output Accounts for commodity flows associated with the construction, services, retail, and household and business moves industrial sectors (Southworth et al. 2011). The outputs are freight O-D flows in dollar and ton values among 131 FAF regions by 43 commodity classes and seven modes of transportation. After the FAF data were released, efforts were made to disaggregate the state and Metropolitan Statistical Area flows into sub-state areas (Anderson et al. 2008, Anderson et al. 2010, Rowinski et al. 2008, Opie et al. 2009, Viswanathan et al. 2008, Harris et al. 2009). Estimating truck O-D flows at local areas, however, are still challenging due to data limitations.

Recently, IMPLAN (Impacts for Planning) input-output data at the ZIP code were released. IMPLAN is an economic impact modeling system that provides commodity flows by 440 industry sectors for U.S., state, county, and ZIP code areas. IMPLAN has been applied for estimating economic impacts of government policy (Norton 2011), industry investment (Calcagno et al. 2003), development project (Douglas and Harpman 1995), and household spending (Bergstrom et al. 1990). IMPLAN has also been applied for estimating freight flows between states (Park et al. 2009) and sub-state regions (Giuliano et al. 2010). Data at the ZIP code area level, however, have not been applied for estimating freight flows. Truck trips can be estimated among ZIP code areas when IMPLAN data are combined with FAF O-D matrix and network data. This approach can help local planners and individuals to save time collecting extensive amounts of data. The estimated truck O-D matrix will be useful to analyze various emission reduction policies.

Summary of Literature Review

Methodologies for estimating truck O-D flows can be classified into two major groups: direct sampling and estimation from secondary data sources. Since direct sampling tends to be time-consuming and labor-intensive, estimation from secondary data sources appeared more attractive for truck O-D estimation. Although there have been studies to estimate truck O-D flows at the sub-

state level, estimation at small areas such as ZIP code has not been applied due to data limitations. IMPLAN input-output data at ZIP code area along with FAF data can be used to estimate truck O-D flows between ZIP code areas.

METHODS APPLIED IN THIS STUDY

This research presents a method to estimate truck O-D flows among ZIP code areas by using IMPLAN input-output data and FAF data. The estimated O-D flows are then used as an input to estimate truck VMT. The estimated VMT are used as an input to an air pollution emissions model, in this case the EMFAC model for California. Several steps are needed to estimate truck O-D flows between ZIP code areas and consequent air pollution emissions from IMPLAN ZIP code area input-output data and FAF data.

Truck Origin-Destination (O-D) Flows Estimation

Estimating truck O-D flows at ZIP code areas in California and between California and other states is the first step for estimating truck VMT. IMPLAN 2008 ZIP code data are the basis for truck O-D flows estimation. Following are the data provided by IMPLAN for a ZIP code area.

- Total commodity output produced in a ZIP code area and total commodity demand attracted to the ZIP code area.
- Foreign exports and foreign imports by the ZIP code area.
- Local supply, which shows commodities that are produced and consumed at the same ZIP code area.
- Domestic exports of the ZIP code area and Domestic imports into the ZIP code area.

As shown above, IMPLAN provides complete trade flows in a ZIP code area. IMPLAN data, however, do not provide origin-destination flows or mode information, which are necessary to estimate truck O-D flows. Therefore, FAF data are used to obtain O-D and mode information. Table 1 shows a comparison between IMPLAN and FAF. It shows that FAF data provide freight O-D flows and mode information among Metropolitan Statistical Areas (MSA) while IMPLAN provides trade flows at ZIP code areas without O-D or mode information. Tables 2 and 3 show detailed information on O-D flows provided by FAF data. The Los Angeles MSA is chosen as an illustration. Table 2 shows O-D flows of domestic and foreign imports in the Los Angeles MSA. California consists of four MSAs and a remainder. The remainder areas include any regions that are not included in the four MSAs in California. Table 2 shows that the Los Angeles MSA has five origins in California and 118 origins outside California for domestic import. In the case of foreign imports, the Los Angeles MSA becomes a domestic origin to deliver the imported goods to domestic destinations. Table 3 shows export components for which the Los Angeles MSA becomes origins for both domestic and foreign exports.

To apply O-D and mode information from FAF data to IMPLAN data, first, IMPLAN 440 sectors are matched to 43 Standard Classification of Transported Goods (SCTG) commodity sectors based on a bridge between the North American Industry Classification System (NAICS) and SCTG (U.S. DOT FHWA 2009). Second, ZIP code data are aggregated to MSA according to the spatial definitions of FAF. In other words, data for all ZIP code areas in each MSA are aggregated to get freight flows for the MSA.

Table 1: Comparisons of IMPLAN Data and FAF Data

Data	Geography	OD information	Mode Information	Sector	Value
IMPLAN	ZIP code	X	X	440 sectors	Dollar
FAF	MSA	O	O	43 sectors	Dollar/Ton

Table 2: Los Angeles MSA Import Components from FAF Data

Los Angeles MSA Domestic Import		Los Angeles MSA Foreign Import		
Origin	Destination	Foreign Origin	Domestic Origin	Domestic Destination
Los Angeles MSA	Los Angeles MSA	Foreign country	Los Angeles MSA	Los Angeles MSA
Sacramento MSA				Sacramento MSA
San Diego MSA				San Diego MSA
San Francisco MSA				San Francisco MSA
Remainder				Remainder
Other States ¹				Other States

Table 3: Los Angeles MSA Export Components from FAF Data

Los Angeles MSA Domestic Export		Los Angeles MSA Foreign Export		
Origin	Destination	Domestic Origin	Domestic Destination	Foreign Destination
Los Angeles MSA	Los Angeles MSA	Los Angeles MSA	Los Angeles MSA	Foreign country
	Sacramento MSA		Sacramento MSA	
	San Diego MSA		San Diego MSA	
	San Francisco MSA		San Francisco MSA	
	Remainder		Remainder	
	Other States		Other States	

Third, proportions of trades among MSAs and dollar to ton conversion factors are estimated from FAF data. Dollar to Proportions of truck class are also estimated from Vehicle Inventory Use Survey (VIUS) data. Fourth, truck O-D flows by commodity sectors are estimated by multiplying trade flows at MSAs obtained from IMPLAN by trade proportions estimated from FAF. Equation (1) ~ (4) show the calculation process for domestic import, domestic export, foreign import, and foreign export, respectively. Each equation is repeated for all 43 SCTG sectors.

$$(1) Trade_{ij}^{T,DL,k} = IMP_j^{DI} \times Prop_{ij}^{T,DI} \times FAF_{ij}^{DI, Ton} \times VIUS_i^k, \quad i = 1\sim 123, j = 1\sim 123, k = 1\sim 7.$$

$$(2) Trade_{ij}^{T,DE,k} = IMP_i^{DE} \times Prop_{ij}^{DE} \times FAF_{ij}^{DE, Ton} \times VIUS_i^k, \quad i = 1\sim 123, j = 1\sim 123, k = 1\sim 7.$$

$$(3) Trade_{ij}^{T,FL,k} = IMP_i^{FI} \times Prop_{ij}^{FI} \times FAF_{ij}^{FI, Ton} \times VIUS_i^k, \quad i = 1\sim 123, j = 1\sim 123, k = 1\sim 7.$$

$$(4) Trade_{ij}^{T,FE,k} = IMP_i^{FE} \times Prop_{ij}^{FE} \times FAF_{ij}^{FE, Ton} \times VIUS_i^k, \quad i = 1\sim 123, j = 1\sim 123, k = 1\sim 7.$$

Where

$Trade_{ij}^{T,DL,k}$ is domestic imports by truck mode and ton value by truck class from origin i to destination j ,

$Trade_{ij}^{T,DE,k}$ is domestic exports by truck mode and ton value by truck class from origin i to destination j ,

$Trade_{ij}^{T,FI,k}$ is estimated foreign imports by truck mode and ton value by truck class from intermediate domestic destination i to final destination j,

$Trade_{ij}^{T,FE,k}$ is estimated foreign exports by truck mode and ton value by truck class from origin i to intermediate domestic destination j to be delivered to foreign countries,

IMP_j^{DI} is the amount of domestic import by dollar value at region j provided by IMPLAN,

IMP_i^{DE} is the amount of domestic export by dollar value from region i provided by IMPLAN,

IMP_i^{FI} is the amount of foreign import by dollar value from region i provided by IMPLAN,

IMP_i^{FE} is the amount of foreign export by dollar value from region i provided by IMPLAN,

$Prop_{ij}^{T,DI} = FAF_{ij}^{T,DI} / \sum_{j=1}^{123} FAF_{ij}^{DI}$ is proportion of domestic imports by truck mode from origin i to destination j,

$Prop_{ij}^{T,FI} = FAF_{ij}^{T,FI} / \sum_{j=1}^{123} FAF_{ij}^{FI}$ is proportion of foreign imports by truck mode from intermediate domestic destination i to final destination j,

$Prop_{ij}^{T,DE} = FAF_{ij}^{T,DE} / \sum_{j=1}^{123} FAF_{ij}^{DE}$ is proportion of domestic exports by truck mode from origin i to destination j,

$Prop_{ij}^{T,FE} = FAF_{ij}^{T,FE} / \sum_{j=1}^{123} FAF_{ij}^{FE}$ is proportion of foreign exports by truck mode from domestic origin i to intermediate domestic destination j to be delivered to foreign countries,

$FAF_{ij}^{T,DI}$ is the amount of domestic import by truck mode from origin i to destination j provided by FAF data,

$FAF_{ij}^{T,FI}$ is the amount of foreign import by truck mode from intermediate domestic destination i to final destination j provided by FAF data,

$FAF_{ij}^{T,DE}$ is the amount of domestic exports by truck mode from origin i to destination j provided by FAF data,

$FAF_{ij}^{T,FE}$ is the amount of foreign export by truck mode from domestic origin i to intermediate domestic destination j provided by FAF data,

$\sum_{j=1}^{123} FAF_{ij}^{DI}$ is the total domestic import at region j provided by FAF data,

$\sum_{j=1}^{123} FAF_{ij}^{FI}$ is the total foreign import at intermediate domestic destination i provided by FAF data,

$\sum_{j=1}^{123} FAF_{ij}^{DE}$ is the total domestic exports from origin i provided d by FAF data,

$\sum_{j=1}^{123} FAF_{ij}^{FE}$ is the total foreign export at origin i provided by FAF data,

$FAF_{ij}^{DI_Ton}$ is dollar-ton conversion factor for domestic import calculated by FAF data,

$FAF_{ij}^{DE_Ton}$ is dollar-ton conversion factor for domestic export calculated by FAF data,

$FAF_{ij}^{FI_Ton}$ is dollar-ton conversion factor foreign import calculated by FAF data,

$FAF_{ij}^{FE_Ton}$ is dollar-ton conversion factor for foreign export calculated by FAF data, and

$VIUS_i^k$ is proportion of truck class by Vehicle Inventory Use Survey.

Fifth, after estimating freight flows between MSA regions, a doubly-constrained gravity model is applied to estimate truck O-D flows between ZIP code areas in each MSA region and between MSA regions. Doubly-constrained gravity models are appropriate when both demand and consumption are given. Although a doubly-constrained gravity model may create distortions in predicting the future due to fixed constraints of demand and consumption (Bruton 1970), the model has been successfully applied to estimate freight O-D flows in various geographies (Levine et al. 2009, Lindal et al. 2006,

Prentice et al. 1998). A doubly-constrained gravity model consists of trip productions/attractions, and a travel distance friction factor (Mao and Demetsky 2002). Trip productions/attractions are obtained from the IMPLAN input-output data. Travel distance friction factors are calculated based on shortest path distances between centers of ZIP code areas which are estimated from the FAF3 network.²

There are two conditions to be satisfied for a doubly-constrained gravity model:

Condition 1: Sum of all trade flows from a region = that region's total supply.

Condition 2: Sum of all trade flows into a region = that region's total demand.

Values meeting these two conditions are achieved via iteration. The results are balanced trade flows.

Sixth, freight O-D flows are converted to number of trucks by applying average payload factors. FHWA provides average payload for truck classes by applying the Vehicle Inventory Use Survey. Appendix Table 1 shows the average payload for California. Truck O-D flows between ZIP code areas by truck class are estimated by dividing the gravity model results with the average payload factors. The estimated truck flows are initial truck O-D flows.

Seventh, the estimated initial O-D flows are adjusted because O-D flows estimated by commodity flows may be different from real traffic flows. Real traffic counts such as the Highway Performance Monitoring System (HPMS) at state and national levels or local survey data are often used to adjust initial O-D flows. FAF data provide Average Annual Daily Truck Traffic (AADTT), which is derived from HPMS. HPMS include traffic count data submitted by each state. So AADTT data are used to adjust the initial truck O-D flows.

AADTT is only available for 2007 or 2040, whereas the scenario of the model is for year 2030. Therefore AADTT for year 2030, which is labeled AADTT30, is calculated by interpolating between the two points. Similarly, link capacity for year 2030, which is labeled CAP30, is calculated by interpolating using 2007 and 2040 data.³ AADTT30 includes truck flows for the nation. But this study only includes truck flows originated from California or destined to California. Therefore, the California portions are calculated from AADTT30. To do that, ton values of the projected freight flows at year 2030 are calculated from FAF O-D data. Equation (5) shows the calculation process.

$$(5) \quad CA_Pro = \frac{\sum_{i=CA, j=1}^{123} Ton_{ij} + \sum_{i=1, j=CA}^{123} Ton_{ij}}{\sum_{i=1}^{123} \sum_{j=1}^{123} Ton_{ij}}$$

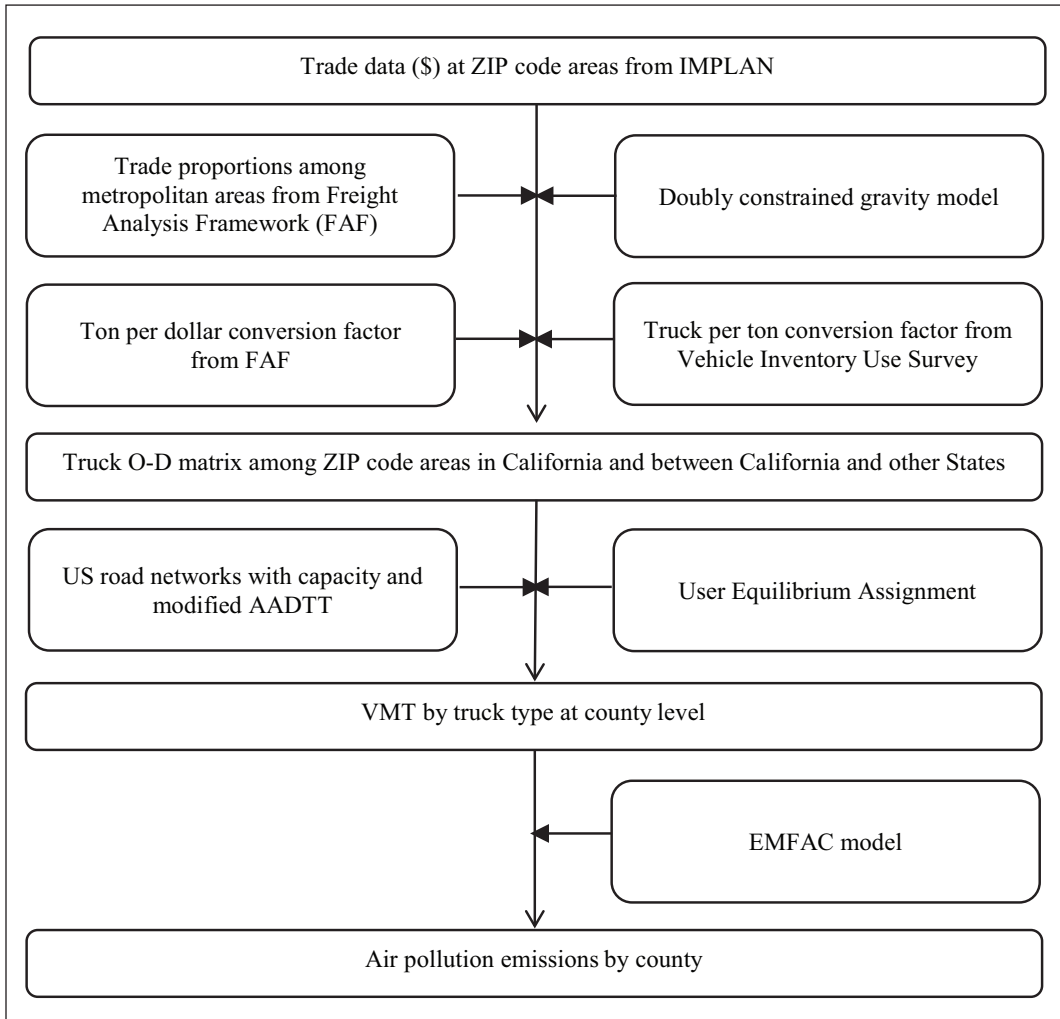
Where

CA_Pro is the proportions of freight flows originated from or destined to California out of total freight flows. i=origin, j=destination.

The calculated proportions are multiplied to the AADTT30 to estimate a modified AADTT30. The modified AADTT30 is further multiplied by VMT proportions in California MSAs to calculate AADTT30 by truck class.⁴ The calculated AADTT30 by truck class is labeled tru_AADTT30. So tru_AADTT30 shows average annual daily truck traffic by truck class originated from or destined to California at 2030. To adjust the initial O-D matrix, an O-D estimation procedure developed by Nielsen (1998) and implemented in TransCAD software (Caliper 2001: page 316) is applied to tru_AADTT30 and CAP30. To convert the truck flows to passenger car equivalent (PCE), the practice from the Southern California Association of Government (SCAG) has applied which involves 1.2 for light truck, 1.5 for medium truck, and 2 for heavy truck as PCE factors. The upper portion of the Figure 1 shows the procedures for O-D estimation.

The estimated truck O-D flows are used as an input for the transportation impact model to estimate VMT on each link of the network. The User Equilibrium (UE) model, a traffic assignment model based on assumed rational behavior of humans that create equilibrium at the network level, is applied to estimate a VMT baseline and to estimate effects of various scenarios. The middle portion of the Figure 1 shows the procedures used to estimate VMT based on the estimated truck O-D flows.

Figure 1: Processes of Estimating Air Pollution Emissions



The estimated VMTs are then used as inputs for the emissions model. Air pollution emissions are estimated by applying the EMFAC model. The bottom portion of Figure 1 shows the procedures for estimating air pollution emissions based on the estimated VMT by truck class. To estimate air pollution emissions, base emission rates are first adjusted by area-specific data such as the Inspection and Maintenance (I/M) program, temperature, and relative humidity. Then total emission inventories are estimated by multiplying the adjusted emission rates by total vehicle activity. These adjustments and estimations are accomplished by applying the EMFAC model.

SCENARIOS

The model developed for this research includes a truck origin-destination (O-D) matrix at ZIP code areas for domestic and foreign trade by commodity sector. To account for the effects of interregional and international trade, the locations of a region’s international gateways for trucking, such as airports, seaports, and border regions, are identified. The model includes road and highway networks that trucks utilize when traveling between O-D pairs. The model is, therefore, appropriate

for identifying and analyzing changes in commodity flow patterns or changes of road network utilization and the corresponding consequences resulting in various air pollution emissions. The key idea is to implement this for various emissions control policy scenarios. Scenario results are compared to projected baseline trends.

Baseline: Future growth of foreign trade in San Pedro Bay (SPB)

This is the reference case that was used to compare and evaluate the various scenario results. The baseline shows network and emissions responses for projected growth paths. The results show the impacts on link volumes and air pollution emissions when trade via local area seaports grows in the near future. Table 4 shows projected growth at San Pedro Bay, which includes the Port of Los Angeles and the Port of Long Beach. Growth rates from 2008 to 2030, which are 170% for imports and 71% for exports, are multiplied by 2008 data for foreign trade via the port of Los Angeles and the port of Long Beach. These results show how the expected growth of trade via the ports affects commodity flows and air pollution emissions. Trade at other regions is assumed to be same as the 2008 value to isolate the effects of the growth at San Pedro Bay.

Table 4: Port of Los Angeles and Port of Long Beach Throughput Demand Forecast (Baseline)

Unit 1,000

	Actuals	Forecast	Increase	
Actual/Forecast TEU	2008	2030	TEU	%
Import Loads	7,328	19,801	12,473	170%
Export Loads	3,470	5,938	2,468	71%

Source: The Tioga Group, Inc. and IHS Global Insight. 2009.

Scenario One: Truck replacement scenario – Replacing older trucks with newer trucks. This scenario utilizes the capability of the EMFAC model, which allows users to modify the characteristics of vehicle populations including vehicle age. The Clean Truck Program (CTP) at the port of Los Angeles and the port of Long Beach has been successful in reducing truck-related emissions around the ports. According to the port of Los Angeles, CTP reduced port truck emissions by more than 80% in 2012 (Port of Los Angeles 2012). CTP was applied to drayage operations (short haul cargo container trips). For Scenario One, it is assumed that a similar program will be applied to all diesel trucks in Los Angeles County so that all diesel trucks in the county would be less than 20 years old in 2030.

Scenario Two: Network & truck improvement scenario – Developing zero emission truck lanes on I-710. Route I-710 is a major freight corridor from the port of Los Angeles and the port of Long Beach to various domestic destinations. Because communities around the freeway have been impacted by air pollution emissions, there have been various studies and plans to reduce emissions while expanding the capacity for truck flows on the freeway. Developing zero emission truck lanes is one of the plans that is relatively cost-effective and technically available. Based on the proposed plans (Metro 2012), it is assumed that four of eight lanes on I-710 will be converted to zero-emission truck lanes by 2030. It is also assumed that hybrid trucks that can be operated by electricity and by diesel engine simultaneously will be operated on the converted lanes. So 50% of the total traffic flows on I-710 will be converted to zero emissions truck flows.

Scenario Three: Land use scenario – Inland port (intermodal facility) at Mira Loma industrial area. Developing an inland port, connected by rail to the existing seaports, has been considered as a long term project to reduce truck traffic and air pollution emissions around the ports and highways. The

Mira Loma industrial area is one of the candidates for such a development (Rahimi et al. 2008). It is assumed that the inland port will begin operations in 2030. A possible development site was found from the SCAG website (Southern California Association of Government 2008: page 135, Exhibit 106). The ZIP code of the location is 91752. It is assumed that 50% of truck flows in the port of Los Angeles and the port of Long Beach are moved from the ports to the inland port for this scenario.

MODEL RESULTS

The model results at two different geographic levels, the Los Angeles MSA and Los Angeles County, are summarized. The Los Angeles MSA includes Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties. The reason that the results at two different geographies are shown is that Scenario one and three identify different implications at different geographies. A sensitivity analysis is also conducted to see how the results are sensitive to different scenarios.

Model Results for the Los Angeles MSA

Results for the Los Angeles MSA are explained in this section. Figure 2 displays a scatterplot of simulated and modified AADTT30 for the Los Angeles MSA. When the simulated and observed volumes agree 100%, the observations fall on the 45-degree line. The correlation coefficient for model results shows about 84% agreement. Table 5 shows the comparison of total volumes in the Los Angeles MSA. The difference in total volume of trucks between simulated and AADTT30 is about 900,000. In other words, total volumes of the modified AADTT30 and simulated agree over 98%. Table 6 summarizes model results of VMT for the Los Angeles MSA. To obtain VMT for the MSA, VMT by vehicle classes for each scenario are aggregated for each county within the MSA. Table 6 shows separate results for two combined counties based on results of Scenario Three. Los Angeles, Orange, and Ventura counties are combined because the three counties have a decrease in VMT for Scenario Three. Riverside and San Bernardino counties are combined because two counties show an increase in VMT for the scenario. Note that there is no change in VMT for Scenario One because of an assumption that VMT of Scenario One is the same as the one of the baseline. In Scenario Two, VMT for vehicle classes of MHD and HHD are reduced by 10,910 miles per day and 16,407 miles per day, respectively, due to the assumption of zero emission vehicle lanes on I-710. Total VMT reductions are 27,317 miles per day, which is a 0.07% reduction.

Figure 2: Simulated Versus Observed (Modified AADTT30) Volumes in Los Angeles MSA

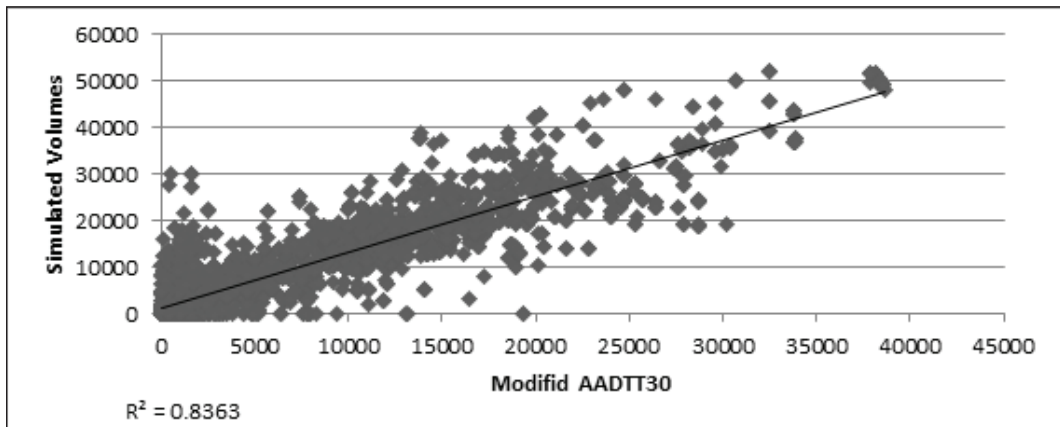


Table 5: Comparison Baseline Total Volumes in Los Angeles MSA

	Total volume of truck		Difference (Simulated-AADTT30)	
	Modified AADTT30	Simulated (Base scenario)	Number	%
Volumes	48,471,251	47,548,530	-922,721	-1.90%

Table 6: Summary of Vehicle Miles Traveled (VMT) Results, Los Angeles MSA

Units: Miles per day

Region	Vehicle class	Baseline	VMT change from scenario			
			1	2	3	
Los Angeles MSA (Los Angeles + Orange + Ventura + Riverside + San Bernardino County)	LDT	23,971,075	-	-	65,143	
	MDT	7,990,359	-	-	20,925	
	LHDT	2,284,008	-	-	2,301	
	MHDT	1,527,658	-	-10,910	2,173	
	HHDT	2,308,083	-	-16,407	6,368	
	Total	Number	38,081,183	-	-27,317	96,910
		%	-	-	-0.07%	0.25%
Los Angeles + Orange + Ventura County	LDT	13,501,956	-	-	-258,623	
	MDT	4,500,652	-	-	-86,700	
	LHDT	1,285,775	-	-	-27,309	
	MHDT	859,145	-	-10,910	-17,353	
	HHDT	1,287,066	-	-16,407	-24,388	
	Total	Number	21,434,594	-	-27,317	-414,373
		%	-	-	-0.13%	-1.93%
Riverside + San Bernardino County	LDT	10,469,120	-	-	323,766	
	MDT	3,489,707	-	-	107,625	
	LHDT	998,232	-	-	29,610	
	MHDT	668,513	-	-	19,526	
	HHDT	1,021,016	-	-	30,756	
	Total	Number	16,646,588	-	-	511,284
		%	-	-	-	3.07%

Note: LDT: Light-Duty Trucks, MDT: Medium-Duty Trucks, LHDT: Light HD Trucks, MHDT: Medium HD Trucks, HHDT: Heavy HD Trucks

Interestingly, in Scenario Three, VMT for vehicle classes are increased when 50% of the truck flows are moved from the ports of Los Angeles/Long Beach to Mira Loma area according to the model results. Total VMT increase is 96,910 miles per day, which is a 0.25% increase. That result may be because infrastructures such as freeways and distribution centers have already been developed for efficient operations around current ports. If an inland port is developed in the Mira Loma area, there would be new developments of highways, major arterials, and distribution centers

to improve network accessibility of the area. Then the network model results may be different than the current results. Even though infrastructures are not fully updated to analyze the scenario, there is an important implication for policy applications from the model results.

Taking transport activities from one place to another may be helpful to reduce environmental problems for the specific area but the benefits may be offset by increased problems in other places. Therefore, analyzing the impacts of policy scenarios in various regions is useful for local area policy makers. More explanations will be developed when the Los Angeles MSA results are compared with the Los Angeles County results later in this paper.

Table 7 displays the results of air pollution emissions applying the network model results for the baseline and three scenarios of the Los Angeles MSA. Note that there are no changes for vehicle classes of LDT, MDT, and LHDT in Scenarios One and Two because the two scenarios only involve MHDT and HHDT. Scenario One shows the biggest reduction in all pollutants among all the scenarios. Notably, NO_x and PM are reduced by 0.54 and 0.04 tons per day, respectively. CO₂ does not change because VMT remains at the same level with the baseline. Scenario Two shows relatively small changes compared with the other scenarios. Because the change in PM is too small compared with the baseline, the results show no change. Scenario Three shows increases in three of the air pollution emissions. PM for total vehicle classes is reduced in the Los Angeles MSA, although total VMT for the region is increased as shown in Table 6. This is because PM reductions in Los Angeles, Orange, and Ventura counties are bigger than the PM increase in Riverside and San Bernardino counties.

In Scenario One, when old trucks in Los Angeles County are replaced with newer models, it will affect air pollution emissions in Los Angeles County and other counties as well. To estimate the effects in each county, truck proportions originated from Los Angeles County are estimated by using the estimated O-D matrix. Table 8 shows the calculated proportions for the Los Angeles MSA. Results for Los Angeles County, for example, show that 73% of the trucks operating in the county including both medium heavy-duty trucks (MHDT) and heavy heavy-duty trucks (HHDT), are originated within the County. In Orange County, 30% of the trucks originated from Los Angeles County. Percentages for other counties can also be interpreted in the same way.

Model Results for Los Angeles County

Table 9 shows VMT for the baseline and VMT changes for the three scenarios. For Scenario One, old trucks are replaced by newer ones but there is no change in VMT because VMT remains the same. For Scenario Two, VMT of MHDT and HHDT are reduced because 50% of truck flows for two truck classes are converted to zero emission vehicle trips on I-710. VMT for other vehicle types remain at the same level.

In Scenario Three, a relatively big decrease in VMT is shown when 50% of truck flows are moved from the ports of Los Angeles/Long Beach to the Mira Loma area. The result is also different than the one for the Los Angeles MSA. Total VMT was increased when Scenario Three was applied in the Los Angeles MSA as shown in Table 6. Part of the reason for the difference is that the Mira Loma area is located in Riverside County. Because this table only includes VMT within Los Angeles County, the result shows decreased VMT.

Table 10 displays air pollution emissions results for the baseline and the three scenarios. There are no changes for vehicle classes of LDT, MDT, and LHDT in Scenario One and Two because these two scenarios only involved MHDT and HHDT. Scenario One shows the biggest reduction in NO_x and Total Organic Gases (TOG) among all scenarios. Scenario Three shows the biggest reduction in CO, CO₂, and PM. Scenario Two shows the least impact in terms of reducing emissions for the county. A part of the reason for small impact of Scenario Two may be that emissions reductions in the specific area do not have much impact for the county as a whole.

Table 7: Air pollution Emissions Results for Baseline and Scenarios in the Los Angeles MSA
Units: tons per day

Baseline						
Vehicle class	LDT	MDT	LHDT	MHDT	HHDT	Total
TOG	28.73	12.09	6.67	1.35	2.98	51.82
CO	85.07	43.16	28.87	12.24	18.92	188.26
NOx	6.15	3.04	14.54	4.55	34.77	63.05
CO2 (1000)	15.84	7.32	2.17	2.41	6.12	33.86
PM	1.8	0.69	0.1	0.22	0.53	3.34
SOx	0.15	0.07	0.01	0.02	0.06	0.31
Difference from baseline						
Scenario 1						
Vehicle class	LDT	MDT	LHDT	MHDT	HHDT	Total
TOG	-	-	-	0	-0.02	-0.02
CO	-	-	-	-0.09	-0.11	-0.20
NOx	-	-	-	-0.31	-0.23	-0.54
CO2 (1000)	-	-	-	0	0	0
PM	-	-	-	-0.01	-0.03	-0.04
SOx	-	-	-	0	0	0
Scenario 2						
Vehicle class	LDT	MDT	LHDT	MHDT	HHDT	Total
TOG	-	-	-	0	0	0
CO	-	-	-	-0.02	-0.03	-0.05
NOx	-	-	-	-0.02	-0.05	-0.07
CO2 (1000)	-	-	-	-0.02	-0.03	-0.05
PM	-	-	-	0	0	0
SOx	-	-	-	0	0	0
Scenario 3						
Vehicle class	LDT	MDT	LHDT	MHDT	HHDT	Total
TOG	-0.01	0	0	0	0.01	0
CO	0.05	0.01	0.01	0.01	0.02	0.1
NOx	0.01	0.01	0.01	0	0.01	0.04
CO2 (1000)	0.02	0.02	0	0	0.01	0.05
PM	0	0	0	-0.01	-0.01	-0.02
SOx	0	0	0	0	0	0

Note: TOG: Total Organic Gases, CO: Carbon monoxide, NOx: Nitrogen oxides CO2: Carbon dioxide PM: Particulate Matter, SOx: Oxides of sulfur.

Table 8: Proportions of Trucks Originated from Los Angeles County

County	MHDT	HHDT
Los Angeles	0.73	0.73
Orange	0.30	0.30
Riverside	0.23	0.22
San Bernardino	0.22	0.21
Ventura	0.35	0.35

Source: estimated origin-destination matrix

Table 9: Vehicle Miles Traveled (VMT) in Los Angeles County

Units: Miles per day

Baseline and Scenarios		Baseline	VMT change from scenario		
			1	2	3
LDT		10,012,255	-	-	-215,567
MDT		3,337,419	-	-	-72,287
LHDT		953,527	-	-	-22,799
MHDT		637,983	-	-10,910	-14,401
HHDT		954,370	-	-16,407	-20,145
Total	Number	15,895,554	-	-27,317	-345,199
	%	-	-	-0.17%	-2.17%

Note: LDT: Light-Duty Trucks, MDT: Medium-Duty Trucks, LHDT: Light HD Trucks, MHDT: Medium HD Trucks, HHDT: Heavy HD Trucks

Sensitivity Analysis

In this section, the results from various sensitivity analyses are explained. Three different levels of implementation of each scenario are applied to examine the sensitivity of the model results.

Summary of the Sensitivity Test Results

The sensitivity test results show that the model works almost linearly for Scenarios One and Two, which means that emissions are linearly decreasing when more old trucks are replaced with new trucks in Scenario One or when more lanes are converted to zero-emission truck lanes in Scenario Two. Scenario Three shows varied results by pollutants and levels. These results would change if a different inland port site other than the Mira Loma area is selected. Overall, the model performs as expected. The sensitivity test results show different implications for each scenario.

Scenario One. TOG, CO₂, PM, and SO_x are not changed by replacing old trucks because truck populations, VMT, and fuel type are the same regardless of the level of implementations. CO and NO_x, however, are changed although the amounts are small. The reason for small changes may be because the EMFAC model has limited capability to assess technology improvement. For example, natural gas trucks would not be included in the EMFAC model unless natural gas trucks are first produced and tested to determine emissions parameters. If alternative fuel trucks such as natural gas trucks become popular, the simulated impacts could be much bigger.

Scenario Two. Emissions for all pollutants except SO_x change because VMT decreases on I-710. But the change is small because the VMT decrease on I-710 is less than 1% of the Los Angeles County total. Although truck traffic on I-710 is heavy, it is a small portion of the amount for Los Angeles County.

Scenario Three. Emissions for all pollutants except SO_x are changed because VMT decreases around the ports of Los Angeles/Long Beach. But the change is small, perhaps because the VMT decrease around the ports is about 1% for all of Los Angeles County.

Important implications of the results are that infrastructure projects at a specific location would not make much impact for the whole County or MSA. Moreover, just replacing old diesel trucks with

Table 10: Air Pollution Emissions Results for Baseline and Scenarios in Los Angeles County

Units: tons per day

Baseline						
Vehicle class	LDT	MDT	LHDT	MHDT	HHDT	Total
TOG	14.02	5.67	3.14	0.7	1.04	24.57
CO	39.63	19.7	14.02	6.46	6.57	86.38
NOx	2.84	1.4	6.78	2.18	11.09	24.29
CO2 (1000)	6.94	3.18	0.95	1.02	2.37	14.46
PM	0.81	0.3	0.05	0.1	0.22	1.48
SOx	0.07	0.03	0.01	0.01	0.02	0.14
Difference from baseline						
Scenario 1						
Vehicle class	LDT	MDT	LHDT	MHDT	HHDT	Total
TOG	-	-	-	0	-0.02	-0.02
CO	-	-	-	-0.07	-0.09	-0.16
NOx	-	-	-	-0.21	-0.18	-0.39
CO2 (1000)	-	-	-	0	0	0
PM	-	-	-	-0.01	-0.01	-0.02
SOx	-	-	-	0	0	0
Scenario 2						
Vehicle class	LDT	MDT	LHDT	MHDT	HHDT	Total
TOG	-	-	-	0	0	0
CO	-	-	-	-0.02	-0.03	-0.05
NOx	-	-	-	-0.02	-0.05	-0.07
CO2 (1000)	-	-	-	-0.02	-0.03	-0.05
PM	-	-	-	0	0	0
SOx	-	-	-	0	0	0
Scenario 3						
Vehicle class	LDT	MDT	LHDT	MHDT	HHDT	Total
TOG	-0.01	0	0	0	0	-0.01
CO	-0.27	-0.12	-0.01	-0.02	-0.04	-0.46
NOx	-0.03	-0.01	-0.01	-0.03	-0.06	-0.14
CO2 (1000)	-0.12	-0.05	-0.02	-0.02	-0.04	-0.25
PM	-0.02	0	0	-0.01	-0.01	-0.04
SOx	0	0	0	0	0	0

Note: TOG: Total Organic Gases, CO: Carbon monoxide, NOx: Nitrogen oxides CO2: Carbon dioxide PM: Particulate Matter, SOx: Oxides of sulfur.

newer diesel trucks would not bring much reduction unless an innovative technology is developed. Applying cleaner fuel such as natural gas would be more promising.

Table 11 shows air pollution emissions results for three scenarios for the Los Angeles MSA. Each scenario includes three different levels, which are -25%, 0%, and 25%. Total Organic Gases (TOG) shows little change for various levels in each scenario. That is because emissions of TOG mostly depend more on vehicle population than VMT. It was assumed that numbers of vehicles are the same for all scenarios. SOx shows no changes across strategies. SOx emissions are calculated by multiplying a weight factor of sulfur in fuel by gallons of fuels consumed. Even though gallons of fuels consumed are changed by different levels of scenarios, the changes are not significant enough to make a difference so that SOx amount remains at the same level. Other pollutants show more reductions when more trucks are replaced in Scenario One or when more lanes are converted to zero-emission truck lanes in Scenario Two. Scenario Three, however, shows mixed results by pollutants and truck classes. NOx, for example, remained at the same level then decreased from

34.78 tons per day to 34.77 tons per day when more HHDT flows were moved from the port of Los Angeles/Long Beach to the Mira Loma area. CO emissions, on the contrary, increased first then decreased when more HHDT flows were relocated. The overall conclusion is that the results are not sensitive to alternative scenarios.

Table 11: Results of Sensitivity Analysis for the Los Angeles MSA

Units: tons per day

		MHDT			HHDT			Total		
		-25%	0%	25%	-25%	0%	25%	-25%	0%	25%
TOG	Scenario1	1.35	1.35	1.35	2.97	2.96	2.96	51.79	51.78	51.78
	Scenario2	1.35	1.35	1.35	2.98	2.98	2.97	51.82	51.81	51.81
	Scenario3	1.35	1.35	1.35	2.99	2.99	2.98	51.82	51.81	51.81
CO	Scenario1	12.20	12.18	12.15	18.87	18.83	18.81	188.16	188.13	188.07
	Scenario2	12.23	12.22	12.21	18.90	18.89	18.87	188.25	188.23	188.21
	Scenario3	12.24	12.25	12.25	18.92	18.94	18.92	188.29	188.35	188.34
NOx	Scenario1	4.40	4.32	4.24	34.66	34.60	34.54	62.81	62.66	62.54
	Scenario2	4.54	4.53	4.52	34.74	34.72	34.69	63.04	63.00	62.97
	Scenario3	4.55	4.55	4.55	34.78	34.78	34.77	63.07	63.08	63.09
CO2 (thousand)	Scenario1	2.41	2.41	2.41	6.12	6.12	6.12	33.83	33.83	33.83
	Scenario2	2.40	2.39	2.38	6.11	6.09	6.07	33.81	33.78	33.76
	Scenario3	2.40	2.41	2.41	6.13	6.13	6.13	33.85	33.89	33.89
PM	Scenario1	0.21	0.21	0.21	0.51	0.50	0.50	3.32	3.32	3.32
	Scenario2	0.22	0.22	0.21	0.53	0.53	0.52	3.33	3.33	3.33
	Scenario3	0.22	0.21	0.21	0.53	0.52	0.52	3.34	3.35	3.35
SOx	Scenario1	0.02	0.02	0.02	0.06	0.06	0.06	0.33	0.33	0.33
	Scenario2	0.02	0.02	0.02	0.06	0.06	0.06	0.33	0.33	0.33
	Scenario3	0.02	0.02	0.02	0.06	0.06	0.06	0.33	0.33	0.33

CONCLUSIONS AND FUTURE WORK

Estimating GHGs and other pollutants is an important basis for regional transportation planning. Treating the trucking sector has been a challenge because of data limitations. This study demonstrated how input-output data at the ZIP code level along with Freight Analysis Framework (FAF) data can be applied to estimate truck flows between sub-state areas and how the estimated truck flows can be used to evaluate various policy scenarios involving reduced air pollution emissions.

The model developed here was used to evaluate three plausible policy alternatives: 1) How much air pollution emissions such as PM and NOx are reduced by replacing old trucks with newer models in Los Angeles County and how great are the impacts throughout the Los Angeles MSA due to a truck upgrade in Los Angeles County. 2) How much air pollution emissions are reduced by introducing zero emission lanes on I-710 in Los Angeles County, 3) How much air pollution emissions are reduced by developing an inland port at the Mira Loma area for Los Angeles County as well as throughout the Los Angeles MSA.

It was found that a truck replacement strategy can be effective for reducing air pollution emissions in both Los Angeles County and the surrounding MSA. Introducing zero emission lanes on a major truck highway can deliver small impacts in the county or surrounding MSA region, although it may have a significant impact to reduce air pollution emissions in specific local areas.⁵

Developing an inland port, however, can increase air pollution emissions in the MSA, although it can reduce emissions around the port area.

By analyzing and comparing the results of three scenarios, various lessons were learned. First, when a policy alternative is considered to reduce air pollution emissions, it is important to make the objectives clear. There can be a strategy that reduces air pollution emissions in a specific area but increases emissions in the surrounding county or MSA. Similarly there can be a strategy that reduces air pollution emissions in the county or MSA, although the reduction in a specific area is not likely. If the objective is to reduce overall air pollution emissions in large areas, the vehicle replacement strategy seems to be promising. If the objective is to reduce air pollution emissions in a specific area such as near highway segments, developing zero emission truck lanes could be a good option. Second, moving transport activities from one site to another could have both positive and negative impacts. Total air pollution emissions may not be changed, although emissions in a local area could be reduced. There are also possibilities to increase overall emissions if proper developments of infrastructure are not implemented. More studies are needed to more thoroughly evaluate land use change.

The model developed here has limitations. First, the model may not evaluate congestion effects properly because only freight flows were included and passenger car flows are not yet added in the assignment. When both passenger car flows and truck flows are added, the results can be different. Second, new technologies can change the model results. For the truck replacement scenario, it was assumed that old diesel trucks are replaced with newer diesel trucks. Recently however, significant natural gas reserves have been developed in the U.S. It is possible that natural gas trucks will be more popular in 2030 because natural gas is likely to be cheaper than diesel. Of course there must be investments in developing efficient trucks, and proper infrastructures must be established to make natural gas trucks popular. Natural gas trucks could not be included in truck replacement strategy because the EMFAC model does not yet include that fuel category. If natural gas trucks are included in the model, there could be more reductions in air pollution emissions. Third, changes in supply chains, such as those prompted by the Panama Canal expansion or opening of the Northern Sea Route, also known as the Northeast Passage, can affect model results. The baseline origin-destination truck flows matrix does not take into account the Panama Canal expansion or opening of the Northern Sea Route. If significant changes in supply chains are assumed due to the opening of the two new routes, freight flows in the Port of Los Angeles and the Port of Long Beach can be changed affecting truck flows and the corresponding air pollution emissions. It is not yet known the extent to which the changes would be a paradigm shift or if most current trends would be continued.

The limitations of the developed model suggest the next steps for the research. Because including passenger vehicles is important for estimating congestion effects, both passenger trips and freight trips need to be combined in the model. The model can also be updated when more fuel types such as natural gas are modeled in the EMFAC model. The model developed here has a capability to test scenarios involving VMT changes at the sub-county levels. The current state of the EMFAC model, however, does not permit us to go to that next step. If and when EMFAC is suitably updated to treat smaller areas, our model will become more useful.

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Endnotes

1. All other MSAs and remainders are labeled as Other States for illustration purposes. Other States includes 118 FAF regions except California.
2. Shortest path distance is used as a friction factor, although travel time may be more realistic. This was the choice because passenger flows were not yet included in the study. Travel time will be used in future work when all vehicle flows are included in the model.
3. $AADTT30 = AADTT07 + ((AADTT40 - AADTT07) / 33) * 23$. Similarly $CAP30 = CAP07 + ((CAP40 - CAP07) / 33) * 23$.
4. The EMFAC model requires VMT by truck class to estimate emissions. Therefore, VMT has to be estimated by truck class. To be consistent with the EMFAC model, VMT by truck is obtained from EMFAC and the proportions are calculated. The calculated proportions are as follows: Light Duty Truck (LDT) = 0.63 (LDT1=0.15, LDT2=0.48), Medium Duty Truck (MDT) = 0.21, Light Heavy Duty Truck (LHDT) = 0.06 (LHDT1=0.05, LHDT2=0.01), Medium Heavy Duty Truck (MHDT) = 0.04, Heavy Heavy Duty Truck (HHDT) = 0.06.
5. The EMFAC model that was applied for estimating air pollution emissions is for county-level estimations; emissions are estimated only at the county level. In Scenario Two, unlike the other two scenarios, emissions reductions occur only on the I-710 link, which is in the scenario area. If only the surrounding area of I-710 is selected, the impact of Scenario Two can be significant. The argument becomes clearer when the % changes of Scenario Two are compared. In Los Angeles County, for example, CO reduction in percentage terms was 0.03%, but 0.06% in the Los Angeles MSA. Estimating impacts in smaller areas below the county level will be a next step of this research.

References

- Al-Battaineh, O. and I. A. Kaysi. "Commodity-Based Truck Origin-Destination Matrix Estimation using Input-Output Data and Genetic Algorithms." *Transportation Research Record: Journal of The Transportation Research Board* 1923 (1), (2005): 37-45.
- Anderson, M. D., G. A. Harris, and K. Harrison. "Using Aggregated Federal Data to Model Freight in a Medium-Size Community." *Transportation Research Record: Journal of The Transportation Research Board* 2174, (2010): 39-43.
- Anderson, M. D., G. A. Harris, S. Jeeredy, S. Gholston, J. Swain, and N. Schoening. "Using a Federal Database and New Factors for Disaggregation of Freight to a Local Level." In *Proceedings of the 10th International Conference on Application of Application of Advanced Technologies in Transportation*, Athens, Greece, 2008.
- Ashtakala, B. and A. Murthy. "Optimized Gravity Models for Commodity Transportation." *Journal of Transportation Engineering* 114 (4), (1988): 393-408.
- Barth, M. "Modal Emissions Modeling: A Physical Approach." *Transportation Research Record: Journal of The Transportation Research Board* 1520 (1), (1996): 81-88.
- Barth, M., and K. Boriboonsomsin. "Traffic Congestion and Greenhouse Gases." *TR News* 268, (2009): 26.

- Benjamin, M. and J. R. Long. "Application of the Global Positioning System (GPS) to the Collection of Vehicle Dynamics Data." Paper presented at the 5th CRC On-road Vehicle Emission Workshop, San Diego, California, 1995.
- Bergstrom, J. C., H. K. Cordell, G. A. Ashley, and A. E. Watson. "Economic Impacts of Recreational Spending on Rural Areas: A Case Study." *Economic Development Quarterly* 4 (1), (1990): 29-39.
- Bruton, M. J. *Introduction to Transportation Planning*. Hutchinson, 1970.
- Calcagno, P., B. Cuffe, L. Schwartz, and J. F. Freymann. "Practical Assessment of the Economic Impact of Healthcare Investment: A Case Study Approach." *Southern Business Review* 28 (2), (2003): 20-28.
- California Environmental Protection Agency Air Resources Board (CARB). "EMFAC2007 Version 2.30 User's Guide." http://www.arb.ca.gov/msei/onroad/downloads/docs/user_guide_emfac2007.pdf, 2007.
- Caliper. *Travel Demand Modeling with TransCAD 4.0*. 2001.
- Cascetta, E. "Estimation of Trip Matrices from Traffic Counts and Survey Data: A Generalized Least Squares Estimator." *Transportation Research Part B* 18 (4-5), (1984): 289-299.
- Cicero-Pernandez, P. and J.R. Long. "Grades and Other Loads Effects on On-road Emissions: an On-board Analyzer Study." Paper presented at the 5th CRC On-road Vehicle Emission Workshop, San Diego, California, 1995.
- Cicero-Pernandez, P. and J.R. Long. "Assessment of Commuting under Grade Loads and Ramp Metering: Preliminary On-road Emissions Findings." Paper presented at the 3rd World Car Conference, Riverside, California, 1996.
- Douglas, A.J. and D.A. Harpman. "Estimating Recreation Employment Effects with IMPLAN for the Glen Canyon Dam Region." *Journal of Environmental Management* 44 (3), (1995): 233-347.
- Gedeon, C., M. Florian, and T. Crainic. "Determining Origin-Destination Matrices and Optimal Multi-product Flows for Freight Transportation over Multimodal Networks." *Transportation Research B* 27 (5), (1993): 351-368.
- Giuliano, G., P. Gordon, Q. Pan, J. Park, and L. Wang. "Estimating Freight Flows for Metropolitan Area Highway Networks using Secondary Data Sources." *Networks and Spatial Economics* 10 (1), (2010): 73-91.
- Harris, G.A., P.A. Farrington, M.D. Anderson, N. Schoening, J. Swain, and N. Sharma. "Developing Freight Analysis Zones at State Level: Cluster Analysis Approach." Paper presented at Transportation Research Board 88th Annual Meeting, Washington, D.C., 2009.
- Holguín-Veras, J., G. List, A. Meyburg, K. Ozbay, R. Paaswell, H. Teng, and S. Yahalom. "An Assessment of Methodological Alternatives for a Regional Freight Model in the NYMTC Region." Report prepared for New York City Metropolitan Transportation Council (NYMTC), 2001.
- Hunt, J.D., and K.J. Stefan. "Tour-based Microsimulation of Urban Commercial Movements." *Transportation Research B* 41 (9), (2007): 981-1013.

- Kahn Ribeiro, S., S. Kobayashi, M. Beuthe, J. Gasca, D. Greene, D.S. Lee, Y. Muromachi, P.J. Newton, S. Plotkin, D. Sperling, R. Wit, and P.J. Zhou. "Transport and its Infrastructure." ed. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press, 2007.
- Lindal, S., D. Olson and G. Alward. "Deriving Multi-Regional Models Using the IMPLAN National Trade Flows Model." MCRSA Presidential Symposium-36th Annual Conference. *JRAP* 36 (1), (2006): 76-83.
- Levine, B, L. Nozick and D. Jones. "Estimating an Origin-Destination Table for US Exports of Waterborne Containerised Freight." *Maritime Economics & Logistics* 11 (2), (2009): 137-155.
- List, G. and M. Turnquist. "Estimating Truck Travel Patterns in Urban Areas." *Transportation Research Record: Journal of The Transportation Research Board* 1430, (1994): 1-9.
- Magbuhat, S. and J.R. Long. "Improving California's Motor Vehicle Emissions Inventory Activity Estimates through the Use of Datalogger-equipped Vehicles." Paper presented at the 6th CRC On-road Vehicle Emissions Workshop, San Diego, California, 1996.
- Mao, S. and M.J. Demetsky. "Calibration of the Gravity model for Truck Freight Flow Distribution." Research Project Report, Mid-Atlantic Universities Transportation Center (MAUTC). <http://cts.virginia.edu/docs/UVACTS-5-14-14.pdf>, 2002.
- Metro. "I-710 Corridor Project." <http://www.metro.net/projects/i-710-corridor-project>, 2012.
- Meyburg, A.H. "Modeling in the Context of Urban Goods Movement Problems." Paper presented at the 2nd Conference on Goods Transportation in Urban Areas, New York, 1976.
- Nielsen, O.A. "Two New Methods for Estimating Trip Matrices from Traffic Counts." *Travel Behaviour Research: Updating the State of Play*. Elsevier, New York, 1998.
- Norton, J. "Education Cuts to Hurt All, Economist Says." *McClatchy-Tribune Business News*. Feb. 22, 2011.
- Opie, K., J. Rowinski, and L.N. Spasovic. "Commodity-Specific Disaggregation of 2002 Freight Analysis Framework Data to County Level in New Jersey." *Transportation Research Record: Journal of The Transportation Research Board* 2121, (2009): 128-134.
- Park, J.Y., P. Gordon, J.E. Moore II, and H.W. Richardson. "A Two-Step Approach to Estimating State-to-State Commodity Trade Flows." *Annals of Regional Science* 43, (2009): 1033-1072.
- Patel, D. and M. Carlock. "A study of the Relative Benefits of On-board Diagnostic and Inspection and Maintenance in California." SAE Technical Paper 951944, California Air Resource Board. <http://www.arb.ca.gov/msei/onroad/downloads/pubs/obdim.pdf>, 1995.
- Port of Los Angeles. "About the Port of Los Angeles Clean Truck Program." http://www.portofla.org/ctp/idx_ctp.asp, 2012.
- Prentice B.E., Z. Wang, and H.J. Urbina. "Driven Demand for Refrigerated Truck Transport: A Gravity Model Analysis of Canadian Pork Exports to the United States." *Canadian Journal of Agricultural Economics* 46, (1998): 317-328.

Rahimi, M., A. Asef-Vaziri, R. Harrison, M. Vaughn-Cooke, K. Salamati, and M. Conrad. "Integrating Inland Ports into the Intermodal Goods Movement System for Ports of Los Angeles and Long Beach." <http://www.mettrans.org/research/final/07-01-Final-Report.pdf>, 2008.

Réos, Alejandro, L.K. Nozick, and M.A. Turnquist. "Value of Different Categories of Information in Estimating Freight Origin-Destination Tables." *Transportation Research Record: Journal of The Transportation Research Board* 1783 (1), (2002): 42-48.

Rowinski, J., K. Opie, and L.N. Spasovic. "Development of Method to Disaggregate 2002 FAF2 Data down to County Level for New Jersey." Paper presented at Transportation Research Board 87th Annual Meeting, Washington, D.C., 2008.

Southern California Association of Government. "Inland Port Feasibility Study." http://www.scag.ca.gov/goodsmove/documents/SCAGInlandPortReport-Final_000.pdf, 2008.

Southworth, F. "The Spatial Accessibility of Truck Terminals in the Presence of Multi Destination Truck Circuits." *Modeling and Simulation* 13 (3), (1982): 1073-1080.

Southworth, F., B.E. Peterson, H.L. Hwang, S.M. Chin, and D. Davidson. "The Freight Analysis Framework, Version 3: A Description of the FAF3 Regional Database and How It Is Constructed." Report prepared for Office of Freight Management and Operations, Federal Highway Administration, Washington, D.C. <http://faf.ornl.gov/fafweb/Data/FAF3ODDoc611.pdf>, 2011.

Swan Wooster Engineering Co. Ltd. "Evaluation of Urban Trucking Rationalization in Vancouver – phase 1 and 2." Report prepared for the Urban Transportation Administration, Transport Canada, Montreal, Canada, 1979.

Tamin, O.Z. and L.G. Willumsen. "Freight Demand Model Estimation from Traffic Counts." In *Proceedings of the 16th PTRC Summer Annual Meeting*, University of Bath, England, 1988.

Tavasszy, L.A., J.E. Stada, and R. Hamerslag. "The Impact of Decreasing Border Barriers in Europe on Freight Transport Flows by Road." In *Proceedings of the 36th Annual Conference of the Transportation Research Forum*, Florida, USA, 1994.

The Tioga Group, Inc. and IHS Global Insight. San Pedro Bay Container Forecast Update. http://www.portoflosangeles.org/pdf/SPB_Container_Forecast_Update_073109.pdf, 2009.

U.S. Environmental Protection Agency (EPA). "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008." <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>, 2010a.

U.S. Environmental Protection Agency (EPA). "Motor Vehicle Emission Simulator (MOVES) User Guide for MOVES2010a." <http://www.epa.gov/otaq/models/moves/MOVES2010a/420b10036.pdf>, 2010b.

Viswanathan, K., D.F. Beagan, V. Mysore, and N.N. Srinivasan. "Disaggregating Freight Analysis Framework Version 2 Data for Florida: Methodology and Results." *Transportation Research Record: Journal of The Transportation Research Board* 2049, (2008): 167–175.

Wisetjindawat, W., K. Sano, and S. Matsumoto. "Commodity Distribution Model Incorporating Spatial Interactions for Urban Freight Movement." *Transportation Research Record: Journal of The Transportation Research Board* 1966, (2006): 41-50.

U.S. DOT FHWA. “Methodology for the Freight Analysis Framework-2: Forecast of Inter-regional Commodity Flows.” http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports8/s5_naics.htm, 2009.

Appendix Table1: Bridge of Vehicle Class Categories Between VIUS and EMFAC

VIUS			EMFAC			Adjusted Avg. payload (lbs)
Vehicle group	Gross Vehicle Weight	Avg. Payload(lbs) for California	Vehicle class	Description	Weight Class(lbs)	
Group 1	Less than 6,000 lbs.	-	LDT1	Light-Duty Trucks	0-3750	2,116
			LDT2	Light-Duty Trucks	3751-5750	
Group 2	6,001 to 10,000 lbs.	2,116	MDT	Medium-Duty Trucks	5751-8500	
			LHDT1	Light-Heavy-Duty Trucks	8501-10000	
Group 3	10,001 to 14,000 lbs.	3,945	LHDT2	Light-Heavy-Duty Trucks	10001-14000	3,945
Group 4	14,001 to 16,000 lbs.	4,560	MHDT	Medium-Heavy-Duty Trucks	14001-33000	11,797
Group 5	16,001 to 19,500 lbs.	5,097				
Group 6	19,501 to 26,000 lbs.	8,518				
Group 7	26,001 to 33,000 lbs.	29,012				
Group 8	More than 33,000 lbs	31,550	HHDT	Heavy-Heavy-Duty Trucks	33001-60000	31,550

Data: Vehicle Inventory Use Survey 2002 (http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports9/s501_2_3_tables.htm#_Toc169399555), EMFAC model

Note: Group 1 of VIUS has too little sample to calculate average payload
 Same payload is applied for LDT1, LDT2, MDT, and LHDT1

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