Freight Shipments, Greenhouse Gases and Polluting Emissions: Implications for California and the U.S.

Final Report

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ABSTRACT

Estimating greenhouse gases (GHGs) and other emissions (especially diesel particulates) is an increasingly important basis for regional policy analysis. According to the EPA (2010b), the transportation sector contributed 27.2 percent of total GHG emissions in 2008, and 50 percent 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 (a prototypical example because of its leadership in air quality policy making) as well as the concurrent effects of various regulation scenarios. In this way, we address questions of sustainability and environmental policy as well as efficiency in freight transportation. We build on important data sources such as, ZIP code-level IMPLAN input-output data and the Freight Analysis Framework (FAF) which provides information on interregional freight movements throughout the U.S. for 2002-2035. We use these data to estimate interregional trade flows between ZIP code areas by applying a gravity model. We translate the estimated interregional trade flows into vehicle miles traveled (VMT) by applying a User Equilibrium model. The estimated VMT in turn are used as inputs to the emissions model to estimate GHGs and other emissions. We demonstrate that interregional freight flow data can be an important data source for emission models. The results are useful not only for estimating GHGs and other emissions based on estimated freight flows, but also for evaluating environmental impacts of policy alternatives. 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 brings a significant impact in a specific area may show a trivial impact in a broader region or vice versa. 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.

1. INTRODUCTION

1.1 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 EMFAC model which is an emissions model for California in which various emissions for major vehicle types are estimated. 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.

It has been estimated that the transportation sector has contributed over 25 percent of U.S. greenhouse gases (GHG) since 1990, as shown in Figure 1-1.[1] Emissions from truck operations have been increasing steadily ever since 1990 and accounted for more than 50 percent of GHG emissions by 2008, as shown in Figure 1-2. Learning more about GHG and criteria pollutants emissions for the trucking mode is a critical aspect of addressing transportation policy in California as well as other states and regions.

There are many difficulties associated with developing an emissions model. Useable

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[1] A more detailed list for California is reproduced in Appendix Table 13.

data are scarce and reliable parameters are hard to judge. Basically, emissions levels are estimated by production of emission factors and by vehicle activities (CARB, 2007; EPA, 2010a). Therefore, researchers have worked on estimating reasonable emissions factors parameters, vehicle activities, or interaction between emissions levels and vehicle activities (Barth and Boriboonsomsin, 2009). The MOVES and EMFAC models have incorporated such research results and have been widely used by government agencies and researchers. Although the two models may calculate incorrect emission estimates for a small region (Barth et al, 1996), the models are useful for identifying trends of emissions levels for large areas.

MOVES2010a is the latest version developed by EPA. Several improvements have been made in the latest version (Bai et al.,2008; EPA, 2009). First, MOVES differentiates vehicle classes by Vehicle Specific Power (VSP) and speed. This is a significant improvement because different emissions rates within each vehicle class can now be estimated. Second, the model includes the most up-to-date emissions parameters. The model also includes vehicle classes consistent with the Highway Performance Monitoring System (HPMS) so that vehicle activity data can be easily adapted to the model.

EMFAC 2007 has been specifically developed for California. The model includes various types of vehicle classes, populations of vehicles by classes as well as vehicle model years. It also includes all necessary information such as speed, temperature, and relative humidity by time of day for each county. Because we plan to first study California and the surrounding areas, we will use the EMFAC model.

Although EMFAC2007 provides comprehensive data, the key factor, vehicle miles traveled (VMT), are estimated by the product of vehicle population and vehicle accrual data. Vehicle population and accrual data are obtained from DMV registration data. Although DMV registration data provide real information about vehicles, there are several disadvantages of the approach. First, vehicles registered in an area are not guaranteed to be operated only in that area. This is an important point for trucks because trucks usually travel long distances beyond an area. Second, most truck companies that have their offices in several areas consolidate registration processes in one DMV office. Third, the data do not provide origin-destination flows so that policy analysis is limited.

The shortcomings may be resolved by using freight flows information because freight flows are estimated between specific origin-destination pairs by industry sectors. Therefore, we expect 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.

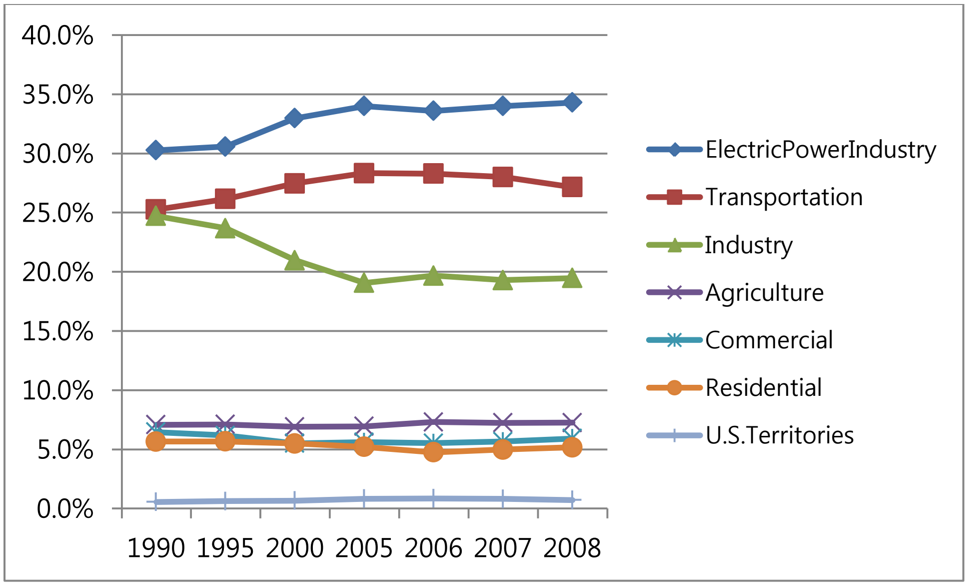


Figure 1-1: GHGs emissions by economic sectors, 1990-2008

Source: EPA, 2010b

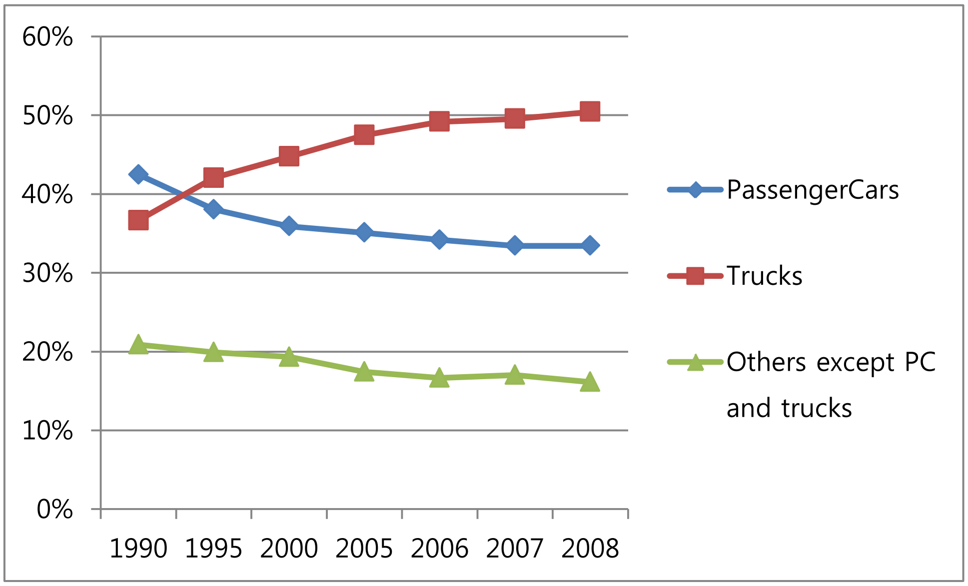


Figure 1-2: GHGs emissions by transportation modes , 1990-2008

Source: EPA, 2010b

1.2 Research objectives

The research objective is to simulate air pollution emissions on road networks associated with truck operations. The study region is California.

There are three sub-goals of the study. First, we estimate truck freight flows between ZIP code areas based on IMPLAN data at the geographic level of ZIP code areas. Estimating spatially disaggregated freight flows is essential for this study. ZIP code areas are the most disaggregated spatial units for estimating freight flows by industry sectors. The estimation is done based on the IMPLAN input-output data and FAF origin-destination commodity flow data.

Second, we set up a highway network model to estimate VMT on the network based on the estimated freight origin-destination (OD) flows. VMT is estimated by truck types. Third, we use the results from the transportation model as inputs to an air pollution emissions model to determine small-area results. We do this for a variety of policy scenarios

2. LITERATURE AND EXISTING MODEL REVIEW

2.1 Truck O-D estimation review

An origin-destination (O-D) trip table is a two-dimensional matrix where each cell represents the number of trips between the corresponding O-D zone pair in the road network for a specific region (Sivanandan, 1991). A truck O-D matrix, accordingly, represents the distribution of truck trips among a set of O-D pairs. Truck O-D matrices are central to freight forecasting in metropolitan areas. As a matter of fact, the majority of the literature assumes all urban freight movements to be conducted by trucking. With this assumption, truck O-Ds would be identical to freight O-Ds except for the measures used. Henceforth we will not distinguish between the two terminologies unless necessary.

O-D matrices provide essential information required for transportation planning, control and management in both passenger and freight sectors. Unfortunately, these matrices are seldom, if ever, known completely and thus need to be estimated. Initially, freight modeling largely adapts passenger traffic modeling techniques epitomized by the classical four-step framework, and truck O-D estimation is no exception. However, it has been widely accepted (Holguin-Veras et al., 2001; Wisetjindawat et al., 2006; Hunt and Stefan, 2007; Giuliano et al., 2010; Chow et al., 2010) that freight modeling differs from its passenger counterpart in the following ways:

- Freight demand is highly disaggregated due to heterogeneity of commodities. The disaggregation refers to not only geographical but also industry sectorial and even firm levels.

- Agent behavior and spatial interactions play a significant role in freight supply chain decisions. The selection of shippers for a customer, carriers for a shipper, routes for a carrier, etc., all stems from and reflects the economic and/or logistical behavior of and interactions between these agents.
- Commercial vehicles do not frequently take independent direct routes between origin and destination; instead, there are trip chains/tours where the composite trips correlate in freight networks. Therefore, truck O-Ds generally cannot be estimated directly.
- Freight flows are unbalanced in the front haul and the backhaul, which leads to empty trips that should be considered in high-quality O-D estimation.

The above characteristics, the so-called “multidimensionality” of freight transportation, add complexity to truck O-D estimation. In fact, sometimes just one of these characteristics can become an issue as will be seen later. Hence it is not surprising that freight O-D estimation has received more attention in recent years.

2.1.1 Classification of truck O-D estimation methodologies

Truck O-D estimation methodologies can be classified via various criteria. A first criterion can be the data involved, which classifies the existing research into two major groups: (1) direct sampling, and (2) estimation from secondary data sources, i.e., O-D synthesis.

Direct sampling employs survey data obtained from straightforward survey methods such as home interviews, questionnaires, license plate surveys, roadside surveys, etc., 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 also exists 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 critical information about O-D distributions and can be updated readily when dynamics are taken into account (Rios et al., 2003). This enables such estimation methods to bypass the need for large surveys and, as a result, they appear attractive and have been intensively studied in the literature.

Without loss of generality, O-D estimation based on secondary data can be interpreted as the “inverse” of the traffic assignment problem, where one aims at finding an O-D matrix that can reproduce the observed traffic or commodity flows on critical links. In highly dense road networks for detailed urban traffic study, available observations tend to be limited and unlikely to cover all the links, which in turn poses too few constraints and underspecifies many potential solutions. Consequently an important question in O-D estimation is how to define and generate the “best” solution. In this regard O-D estimation methodologies can be divided into three broad categories: traffic modeling approaches (gravity models, entropy models, and equilibrium models), statistical inference approaches, and mathematical programming approaches. Traffic modeling approaches utilize traffic modeling concepts of information minimization or entropy maximization. Statistical inference approaches implement the ideas of maximum likelihood, generalized least squares, or Bayesian inference. Mathematical programming approaches formulate the estimation problem as linear or nonlinear programming models, and solve them with efficient algorithms in operations research.

As mentioned in the previous section, freight O-D estimation is similar, but not equivalent to, passenger O-D estimation. While the above methods work well for the latter, they are fundamental and inadequate for the former. A pragmatic philosophy is to customize the above methods to meet the needs of freight O-D estimation. The resulting research varies with respect to the modeling platform employed. There have been two major categories from this viewpoint: commodity-based and vehicle-trip-based (Holguin-Veras and Thorson, 2000). The commodity-based approach models commodity types and then converts commodity flows to vehicle trips using spatial interaction models and/or complementary empty trip models, whereas the vehicle-trip-based approach models vehicle trips directly and explicitly. Both approaches have pros and cons. Freight transportation naturally arises from human economic and social activities, therefore commodity-based models can better capture the underlying economic drivers and behavioral mechanisms. Also, it is convenient to model multimodal systems by tracking the classified commodity flows. In terms of input and output of the models, however, the commodity-based approach requires large volumes of commodity data for calibration, and worse, empty trips may not be easy to assess. On the other hand, calibration data for vehicle-trip-based models is easy to collect, but the approach itself does not reflect cargo features directly and so multimodal attributes can be a problem. The appropriate approach to use, of course, should be determined case by case. In fact, freight transportation is so complex that adapting any existing approach has problems. Recent literature has also included alternative approaches that abandon the classical four-step framework. Though real-world applications are rarely reported, these approaches may reveal useful perspectives that should not be ignored.

Freight O-D estimation approaches also vary regarding whether to account for traffic evolution over time. Because of data limitation, however, dynamic O-D estimation is not a part of this study and so will not be discussed.

2.1.2 General O-D synthesis methodologies

Traffic modeling approaches

The first class of traffic modeling approaches involves gravity models. These often include the idea of estimating trip distributions via a proportional or all-or-nothing assignment. Depending on how the total number of trips produced at and attracted to various transportation analysis zones (TAZs) is constrained, this class can be further divided into three types: the unconstrained gravity model, the singly (either origin or destination) constrained gravity model, and the doubly constrained gravity model. In such models, traffic counts are mapped to O-D elements with a function whose parameters can be calibrated with regression techniques. Generic constraints and objective are flow conservation and minimization of the differences between observed volumes and estimated volumes, respectively. Both linear and nonlinear regression techniques have been proposed. The former can be found in Low (1972), Holm et al. (1976), Gaudry and Lamarre (1978), and Smith and McFarlane (1978); the latter are in Robillard (1975) and Hogberg (1976).

The main criticism of gravity models is that they enforce gravity patterns on the trip matrix and so to some extent waste the information contained in the observed traffic counts. A solution to this problem is entropy models originally developed by Van Zuylen and Willumsen (1980). This class generally introduces an a priori matrix called the target O-D matrix to attain an a posteriori O-D matrix based on two ideas: the first is to add as little external information as possible to the target O-D matrix, i.e., to minimize information; and the second is to make as much use as possible of information contained in real counts, i.e., to maximize entropy. Both ideas are equivalent in the sense that the desired O-D matrix is the most likely one consistent with available real information. The target O-D matrix can be designed with old data and a reasonable source is an O-D table for the base year.

Entropy models differ by the assignment rules employed, proportional (Willumsen, 1978; Van Zuylen and Willumsen, 1980) or equilibrium-based (Nguyen, 1977; Jornsten and Nguyen, 1979; LeBlanc and Fahrangian, 1982). Here is how the proportional assignment works: each link flow is divided proportionally among its incident O-D pairs, which enables the calculation of the probability that this portion of flow comes from a specific O-D pair; one can then search for the a posteriori trip matrix that maximizes the overall probability of reproducing the observed traffic counts. One problem with this approach lies in its limited application to congested networks, where the existence of bottleneck queues may invalidate the reliability of fixed proportions. Although Fisk (1988) suggests an extension to the case of congestion by imposing user-equilibrium constraints, the resulting problem is hard to solve due to the nonconvex structure of the variational inequalities, and hence this contribution is only of theoretical interest. Another problem concerns the role of the target matrix, which is simply to provide an initial condition and thus the traffic counts are given priority. But both the target matrix and the observed traffic counts present some level of uncertainty in reality, therefore it is not always a strong assumption that the observed traffic counts are more trustable and the above approach would not induce larger errors than otherwise. As a matter of fact, Brenninger-Gothe et al. (1989) show that a weighting is made, explicitly or implicitly, in almost every estimation process, and there is no “best” way to specify the weights in proportional assignments.

As an alternative, equilibrium methods seek the user-optimally assigned matrix based on the so-called “Equilibrium Principle” which assumes each user to behave rationally and non-cooperatively so that his/her transportation cost can be minimized (Wardrop, 1952). Nguyen (1977) is the first to formulate the equilibrium based O-D estimation problem. With this formulation, the solution will reproduce the observed traffic counts if these observations are at equilibrium, but under-specification remains an issue. Following up this work, Jornsten and Nguyen (1979) propose a formulation of entropy maximization that does not require a target O-D matrix. In the same spirit of seeking for a unique O-D matrix, LeBlanc and Fahrangian (1982) formulate a least squares model that obtains the O-D matrix not only user-optimal but also deviates least from a known target matrix. Contrary to the proportional approach, equilibrium models determine the route choice proportions endogenously and hence can be and have been widely adopted for congested networks. An elaborate review of this approach is presented in Yang et al. (1994).

Statistical inference approaches

These models jointly use traffic counts and the target matrix to estimate the desired O-D matrix, and a common characteristic is to trade off the aforementioned sources. The main advantage is that they consider the stochastic nature of the problem directly, and possess the large sample properties of (asymptotic) unbiasedness, normality and efficiency.

The maximum likelihood approach assumes the target O-D matrix and the observed traffic counts to be observations of two independent random vectors. The motivation is to maximize the probability of realizing the target O-D matrix and the observed traffic counts conditional on the O-D matrix to be estimated. A representative example is Spiess (1987). In this paper, a full target matrix is obtained by sampling Poisson variables and three optimization models are suggested for estimation. All the models have similar objective functions, but differ in constraints: the first model assumes proportional assignment and treats link flow consistency as constraints; the second model is doubly constrained, i.e., it incorporates both trip assignment and trip distribution constraints; the third model eliminates the consistency requirement. The first two models can reproduce the observed traffic counts but are computationally demanding, whereas the simpler third model may reduce to an approximate maximum likelihood model if the assumption of mutually independent traffic counts is weakened. Efficient algorithms are designed for all three models. Other works include Geva et al. (1983), Watling and Grey (1991), and Watling and Maher (1992). All have the nice property of definite feasibility regardless of the target matrix, which is not guaranteed for entropy maximization methods.

The generalized least squares approach views the target O-D matrix and the traffic counts as stochastic response variables to the desired O-D matrix. The errors associated with the target O-D matrix and the traffic counts reflect the respective dispersion, and are assumed to be random and mutually independent. Given the dispersion matrices as parameters, an estimator can then be formed by minimizing the weighted mean square errors depending on the dispersion matrices. Cascetta (1984) derives expressions for the mean and variance of the estimator when nonnegativity constraints on the estimated O-D matrix are not binding. The resulting O-D estimation is demonstrated to be better than the maximum entropy approach even if the dispersion matrices are not exact but heavily approximated. The relative independence of the results from the dispersion matrices may be explained by Cascetta (1984) and Bierlaire and Toint (1995), whose experiments show that the models appear much more sensitive to variations and inaccuracies in the target O-D matrix and the traffic counts than to values of the parameters. Bell (1991) addresses the issue of active nonnegativity constraints by taking the corresponding Lagrange multipliers to the objective function. Yang et al. (1992) extend the basic model to a bilevel programming model combining generalized least squares and equilibrium assignment. The observed traffic counts are not required to be at equilibrium in this paper, and several special cases of the parameter values are identified to coincide with Nguyen (1977) and Fisk (1988). The relations between the generalized least squares estimator and other estimators have been discussed by Dolby (1972) and Bell (1984), and the main findings are twofold: (1) the generalized least squares estimator is actually the maximum likelihood estimator if the dispersion matrices are multivariate normally distributed; (2) the generalized least squares approach can provide a good approximation of the minimum information estimator proposed by Van Zuylen and Willumsen (1980).

When considering the equilibrium assignment, there always exist such questions as whether the observed traffic counts are of the user-equilibrium pattern, what effects that would make, and how to convert observations in disorder to be at equilibrium. Yang et al. (1994) partly answer these questions by claiming that traffic counts for feasible underspecified equation systems are at equilibrium, but overall no standard procedure to adjust arbitrary traffic counts has been known.

The Bayesian inference approach treats the target O-D matrix as a prior distribution of the estimated O-D matrix, the observed traffic counts as sample information for the likelihood distribution, and the desired O-D matrix as the posterior distribution. Given the target O-D matrix and the observed traffic counts, one can then use Bayes' rule to calculate the O-D estimations. Maher (1983) examines a logarithm expression of the Bayesian equation and verifies the equivalence of this approach and the entropy method when the posterior distribution is multivariate normal. Proportional assignment is assumed in this work. According to Cascetta and Nguyen (1988), the Bayesian inference approach resembles the maximum likelihood approach and the generalized least squares approach as well, except that the roles of the target O-D matrix differ: for the Bayesian approach, it is a random vector associated with the posterior distribution, whereas for the other two approaches, it is the parameter set corresponding to the sampling likelihood function.

Mathematical programming approaches

Equilibrium based models are credited for their applicability to congested networks, but the majority of this class have a nonlinear and bilevel structure that determines the O-D estimation and the equilibrium assignment on two interconnected levels. Such a complicated structure brings about computational difficulty and, accordingly, necessitates exclusively designed techniques. Mathematical programming methods have found their place in this field.

One approach is to apply heuristics or gradient algorithms and iterate between the two levels until a predefined convergent condition is satisfied. Some studies previously discussed follow this way, including Jornsten and Nguyen (1979), LeBlanc and Farhangian (1982), and Fisk (1988). Jornsten and Nguyen (1979) utilize Benders decomposition and test three small numerical examples. LeBlanc and Farhangian (1982) solve the lower level problem, i.e., the equilibrium based assignment problem, by the Frank-Wolfe method. Fisk (1988) sketches out a solution procedure, but does not report any applications. Relevant work can also be found in Spiess (1990), Drissi-Kaitouni and Lundgren (1992), Florian and Chen (1993), Chen (1994), Yang (1995), Codina and Barcelo (2004), and Lundgren and Peterson (2008). Specifically, Spiess (1990) designs an approximation algorithm with proportional assignment which, though not convergent, works satisfactorily and is later adopted in a commercial transportation planning system. Drissi-Kaitouni and Lundgren (1992) suggest general descent algorithms as a proper resort for large-scale networks. Florian and Chen (1993) show that a descent direction of Gauss-Seidel type may produce closer solutions. Chen (1994) analyzes an augmented Lagrangian method as well as a heuristic Gauss-Seidel type method, which are demonstrated to suit small networks and large networks, respectively. Yang (1995) studies two heuristic algorithms that converge fast, namely a heuristic iterative algorithm and a sensitivity analysis based heuristic algorithm. Codina and Barcelo (2004) develop a subgradient method for non-differentiable problems. Lundgren and Peterson (2008) adopt a projected gradient method where the search direction is computed by approximating the Jacobian matrix for the link flows. The order approximation of the Jacobian matrix is done by solving a set of quadratic programs.

Another approach is to consider computationally tractable formulations, mainly referring to linear programming. Colston and Blunden (1970) are among the first to study O-D distributions with linear programming methods. Unfortunately, the attempt fails to perform well as the applications to general transportation problems do in practice. No successful trial has come up until the 1990s. Sherali et al. (1994a) formulate the problem as a path-based linear model, where the objective coefficients are defined as the time impedances or costs on the routes corresponding to each O-D pair, or a constant number big enough for the rest routes; the constraints include equilibrium and nonnegativity. The optimal solution to this problem, if it exists, is shown to be of user-equilibrium pattern and thus can reproduce the observed flows. Sherali et al. make two successive modifications of the preliminary model to accommodate inconsistent flow data and prior trip tables, respectively. Given that there are exponentially possible path variables, column generation techniques are employed to implicitly enumerate all feasible solutions. The subproblems are essentially shortest path problems and so can be solved efficiently. The model assumes a complete set of observed flows for the entire network, and hence there naturally arises the question how to obtain the desired O-D matrix in case of missing link flows. Improved versions in this respect appear in Sherali et al. (1994b) and Sherali et al. (2003), where the objective coefficients are updated by solving both linear and nonlinear subproblems iteratively, or approximating the nonlinear model with a sequence of linear models. The efficiency of such approaches has been tested on real road networks.

2.1.3 Truck O-D estimation methodologies

Early studies on truck O-D estimation generally resemble passenger O-D estimation and follow the methodologies previously discussed. For instance, gravity models can be found in Meyburg (1976), Ogden (1978), Swan Wooster (1979), Southworth (1982), Ashtakala and Murthy (1988), and Tamin and Willumsen (1988); mathematical programming models can be found in Gedeon et al. (1993) and List and Turnquist (1994); and heuristic solution techniques can be found in Tavasszy et al. (1994) and Al-Battaineh and Kaysi (2005).

The problem with early studies is that the unique features of freight transportation are largely ignored. Taking gravity models for example, the core assumption of these models is the monotonically decreasing pattern of trip length distribution, which conforms to the rational behavior of passenger transportation but deviates from reality in the case of freight transportation (Jack Faucet Associates, 1999). The complexity of freight modeling has motivated the development of exclusive models and methods.

Data extraction methods

Secondary freight flow data generally have three problems: first, different data sources reveal different aspects of freight flows, but hardly can any single source describe the complete flows regarding an area; second, they are not equally available for various modes; and third, most are at an aggregate level whereas the desired analysis requires more disaggregate data.

Giuliano et al. (2010) attempt to address the first two issues for commodity-based models. The underlying logic is to estimate regional commodity-specific O-D matrices by integrating international, interregional and intraregional trip attractions and productions. The suggested data sources include IMPLAN, CFS, WISER, WCUS, and ITMS. For any area, its flow set can be divided into five parts, namely international import, international export, domestic import, domestic export, and intraregional flows. Since IMPLAN contains information about import/export totals by industrial sector, to get international and interregional flows one can first derive each flow part proportionally from IMPLAN, and then assign the domestic import/export flows to mode with CFS and ITMS, and international import/export flows with WCUS and WISER. The subsequent question is how to account for the intraregional flows. To do this the authors generate intraregional productions and attractions utilizing a regional input-output transactions table as well as employment data for small areas. The approach is demonstrated applicable to a geographic level as fine as traffic analysis zones. Once the interregional flows and intraregional productions and attractions are obtained, flows are converted from dollars to tons. Intraregional trips can be distributed together with a further conversion to truck trips with conventional gravity models. Since an implicit assumption is that intraregional flows are conducted by truck, the total number of non-truck trips generated by some baseline model may well be used as a control. The distribution of interregional trips is confined to a limited number of zones in the region to reflect their import/export shares, which are based on attracted trips at internal TAZs.

Traditionally, the third issue mentioned above is solved by rough spatial disaggregation, i.e., by factoring both the rows and columns of a given aggregated O-D matrix simultaneously and directly. The row and column split coefficients can be determined with various sources, socioeconomic data, trip generation equations, disaggregated VMT, and individual traffic counts, to name a few. Easy to implement as it is, this approach ignores the possible effect of special disaggregate-level interactions that are hidden or averaged out at the aggregated level. To overcome this problem, Horowitz (2009) proposes a new disaggregation method with traffic counts as the secondary data source and Fratar biproportional least-squares models as the estimation technique. Six models are developed to satisfy different needs. In the case of perfectly aggregated O-D information, the model seeks the solution that deviates from ground counts least and matches the given O-D matrix exactly. In the case of approximately aggregated O-D information, flow conservation constraints are moved to the objective function and thus a relaxation problem is formed compared with the previous case. A variation for these basic models considers the effects of trip utility or spatial separation, and logit gravity models of destination choice are introduced to calculate the correction coefficients and thus enhance the objective functions. The other two variations for the case of approximate aggregated O-D information incorporate link-to-link flows and special zone-to-zone flows, respectively. It is pointed out that further variations such as factor bounds and congestion can also be handled by adding new constraints or combining equilibrium models. The resulting models are all nonlinear optimization problems and an iterative bilevel algorithm is designed for solution. The method can be applied to both commodity based and vehicle-trip based approaches.

A more modeling-specific contribution but in the same spirit of data saving, Sivakumar and Bhat (2002) introduce an intuitive fractional split distribution model which later enlightens the development of a trip-chaining model in Wisetjindawat et al. (2006). The main difference from earlier studies is that this framework does not require production and consumption levels at each geographical analysis zone to be determined simultaneously in the commodity generation step; instead, consumption data suffices, and the allocation of production levels (in fractional form) at the associated origins is left to the fractional split distribution model, which describes the relationship between the desired fractions and zonal explanatory variables as normalized multinomial logit functions. Each relationship function is composed of two parts: a composite size measure which represents the number of elemental commodity production points within a specific zone, and a composite impedance measure which represents the marginal deterrence between a specific O-D pair. The parameters involve both scalars and vectors, and can be obtained by maximizing a set of quasi-likelihood functions. The fractional split approach saves production data but captures the essence of demand-driven freight movements and hence appears more trustable than gravity models. Indeed, Sivakumar and Bhat (2002) showed an empirical application that produces better results than the gravity models. A drawback is the limited application to interregional (statewide) commodity flow analysis.

Trip-chaining and behavioral models

One major concern of conventional O-D estimation methods is that they confine analysis to a zonal level, which challenges the incorporation of agent behavior and spatial interactions. Trip-chaining, a result of the underlying logistical decisions, tends to be ignored as well. A plausible improvement can be agent-based analysis where the smallest analysis unit is an individual firm rather than a geographical zone.

McFadden et al. (1986) is perhaps the earliest to work on agent behavior for commodity flows. The behavioral element of the proposed model is in essence a logistics model that jointly determines mode choice and shipment size by minimizing inventory costs. Abdelwahab and Sargious (1985) use a discrete choice model for the same purpose. A variation of this model is designed by Holguin-Veras (2002), where the formulation is discrete-continuous in that shipment size variables are treated as continuous. A common limitation of these models is that they merely account for the interaction between two freight agents. Boerkamps et al. (2000) illustrate the procedures to incorporate the interactions among all agents but no formulations have emerged.

Wisetjindawat et al. (2006) shine a light on comprehensive behavior modeling. Analogous to conventional studies, they first generate the production amount of a commodity for each shipper and the consumption amount of a commodity for each customer. These amounts constitute the input of the core model -- the distribution model, which then calculates the commodity flow between each shipper-customer pair by multiplying the total consumption of a commodity of a customer by the fraction of him/her purchasing the commodity from a shipper. The fraction can be decomposed into three parts, namely the distribution channel probability, the zone choice probability, and the shipper choice probability. The distribution channel probability reflects the supply chain structure of freight flows and can be determined from empirical data. The zone choice probability reflects the spatial interaction in location choice and can be obtained via a spatial mixed logit model. The shipper choice probability reflects the purchasing relationship between shipper-customer pairs and can be estimated ideally from survey data or approximately by weighting the production amount based on utility functions. Due to the complexity of the model, parameter calibration is conducted with simulated maximum likelihood techniques.

In a supplementary paper, Wisetjindawat and Sano (2003) further develop a framework for conversion of the commodity flows to vehicle movements. Three steps are taken sequentially: first, the delivery lot size and frequency are determined for each shipper-customer pair and each commodity with an unconstrained total cost minimization model; second, the carrier and vehicle types are selected for each shipper-customer pair and each commodity with a utility-based nested logit model; and third, the delivery route is chosen for each shipper with a vehicle routing model constrained by both capacities and time windows. Tour selection can also be found in Donnelly (2007), where vehicles are first allocated and filled according to average payload weight and traveling salesman algorithms are then utilized for optimization.

More recently, the consideration of trip chains has led to a new family of truck O-D estimation approaches as an alternative to the four-step framework – tour-based microsimulation where a tour is the smallest analysis unit. Relevant work can be found in Gliebe et al. (2007), Hunt and Stephan (2007), and Wang and Holguin-Veras (2008, 2009). Gliebe et al. (2007) creates an intra-urban commercial vehicle model that incrementally builds tours and reproduces observed traveling patterns. Hunt and Stephan (2007) design a multi-modal, multi-sector, agent-based framework that covers attributes including tour generation, vehicle and tour purpose, tour start, next stop purpose, next stop location, and stop duration. Wang and Holguin-Veras (2008, 2009) propose an efficient discrete choice model to generate a candidate tour set, a heuristic algorithm to select the desired tours, and an entropy maximization formulation to determine the flows along each tour.

All the above approaches are disaggregated except for Wang and Holguin-Veras (2008, 2009). The most outstanding advantage is that they incorporate the complex relationships involved in freight transportation at a micro level and thus is responsive to small-scale changes, whereas some obvious disadvantages may be the intensive data and computational efforts required for calibration, validation, and solution.

Empty trip models

Empty trip models are usually designed to overcome the inability of implicitly incorporating empty trips in commodity-based approaches. The evolution of such models has gone through three phases: the naïve proportionality model, models that assume a direct correlation of empty trips in one direction to commodity flows in the reverse direction (Noortman and van Es, 1978; Hautzinger, 1984), and models that take trip chaining into consideration (Holguin-Veras and Thorson, 2003; Holguin-Veras and Patil, 2008).

In the naïve proportionality model, the average payload (tons per trip) ratio is assumed to be constant for any trip (loaded or empty) produced per unit of commodity flow, hence the total number of vehicle trips between an O-D pair can be expressed as the commodity flow (in trips) divided by this constant ratio. Simple and broadly applied though it is, this model is problematic since the number of empty trips is assumed to merely rely on the commodity flow in the same direction, which implies empty trips would remain unchanged when the reverse flow changes, but of course, contradicts real observations.

A first improvement is achieved in Noortman and van Es (1978), where the number of empty trips is obtained by multiplying the commodity flow in the reverse direction by a constant. This leads to a more reasonable formulation that relates the total trips between an O-D pair to the commodity flows in both directions. A by-product of this model is that the total trips between the complementary O-D pair (the pair obtained by exchanging the origin and the destination of a pair) may deviate significantly from that between the O-D pair in question, whereas empirical evidence shows a consistency between the two even in extreme cases. In light of this, Hautzinger (1984) makes a second improvement by introducing bi-directional empty trip ratios to the model. The ratios are non-constant, but can be calculated with positively related functions of commodity flows in the reverse direction. In this way equality of the total trips is guaranteed. There exists a problem in both improvements, though: trip chains have been ignored.

Holguin-Veras and Thorson (2003) introduce the concept of order of a trip chain model which sets the basis for developing more complicated models and unifies the above models as well. The concept refers to the number of transient stops before reaching the final destination in a commodity flow. By this definition the above models are all zero-order, whereas the one developed by Holguin-Veras and Thorson is first-order. For simplicity, the summation of all higher-order empty trips is approximated by multiplying the expected first-order empty trips by a constant for all O-D pairs, and the zero-order empty trips are expressed as the same function in Noortman and van Es's model. As a result, the desired number of empty trips between an O-D pair is a linear function of the given commodity flows with four types of parameters: the constant for higher-order empty trips, the probability of a zero-order trip chain, the probability of the destination chosen as the next stop in a tour, and the probability of not getting a load. Two ways to calibrate the parameters are suggested: an unconstrained search that finds the parameters fitting a given data set best, and an error minimization model constrained by replication requirements on specific measures. An analysis of the relationships between the first-order model and the previous models reveals that Holguin-Veras and Thorson's model mediates between Noortman and van Es's model and Hautzinger's model regarding the difference of a commodity flow from the reverse flow.

Holguin-Veras and Thorson's empty trip model is later integrated into doubly constrained gravity models for freight O-D estimation (Holguin-Veras and Patil, 2007, 2008). Three versions are developed: single-commodity, multi-commodity with parameters calibrated by minimizing total squared truck traffic errors, and multi-commodity with parameters calibrated by minimizing total squared errors in both loaded and empty link volumes. Comparative experiments confirm the superiority of models incorporating empty trips over otherwise and the superiority of the multi-commodity formulation over the single-commodity formulation in their ability to reproduce the observed traffic counts.

We used secondary data sources to estimate the truck O-D matrix. We applied traffic modeling approaches, including a doubly-constrained gravity model and equilibrium model, in terms of the O-D estimation methodology. Our approach is commodity based. We adjusted the estimated O-D matrix by minimizing the differences between estimated volumes from secondary data and observed volumes which are AADTT obtained from

FAF data. When the O-D matrix estimated from the secondary data are adjusted with AADTT, the adjusted truck O-D matrix includes empty truck trips because AADTT obtained from FAF data includes empty trips although we do not estimate empty trips separately.

2.2 Air pollution emissions review

2.2.1 Factors affecting air pollution emissions

Air pollution emissions caused by transport activities can be grouped into two types: greenhouse gasses (GHGs) and other pollutants. GHGs include Carbon dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O) from fuel combustion and F-gases (fluorinated gases) from vehicle air conditioning (Kahn Ribeiro et al., 2007). Other pollutants are total gaseous Hydrocarbons (HC), Carbon Monoxide (CO), Oxides of Nitrogen (NOx), Particulate matter (PM_{10}, $PM_{2.5}$), and Oxides of sulfur (SOx) (CARB, 2007; EPA, 2010a).

Efforts have been made to estimate GHGs and other pollutants caused by transport activities. Estimation processes reflect an understanding of which factors affect emissions rates. As shown in Figure 2-1, air pollution emissions rates from freight movements in an area are affected by three prominent factors:

- Volumes and types of production
- Ambient conditions
- Vehicle operating characteristics

The volumes and types of production determine the amounts and types of freight flows within and among surrounding areas. For example, agricultural products and related materials would be the types of freight transported in and out of a rural area that consists mostly of farms. If there are many productions in an area, freight flows would likely increase. Amounts and types of freight flows will affect the number of transport activities and types of transport equipment used which, in turn, affect the amount of air pollution emissions.

Ambient conditions such as grades of roads, temperature and relative humidity of an area are important factors determining air pollution emissions rates (Lents et al., 2011). As grades of roads change, vehicles accelerate and decelerate accordingly resulting in changing emission rates. When vehicles go uphill, engines generate more power at low speeds causing imperfect combustion which creates more exhaust emissions. When vehicles go downhill, brakes would be used more frequently resulting in more emissions of particulate matter (PM). Ambient temperature and relative humidity are important factors related to evaporative emissions.

Vehicle operating characteristics such as vehicle age, types of air pollution control devices equipped with the engine, driver's habits, and congestion levels are important factors determining air pollution emissions rates.

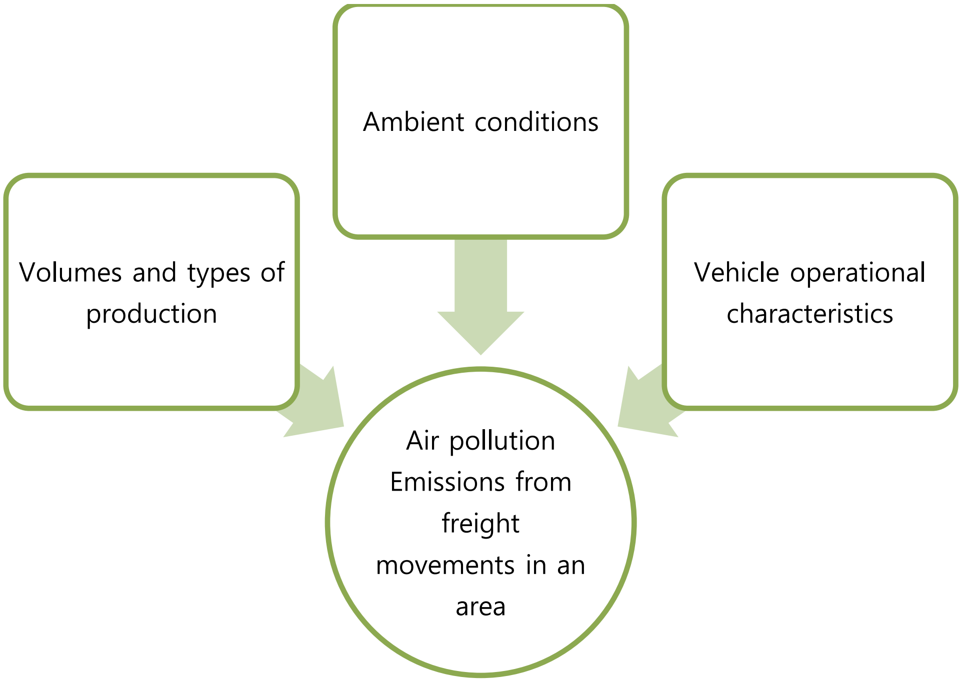


Figure 2-1: Factors affecting air pollution emissions rates from freight movements

Modeling practices reflect the current understanding of the relationships between emissions rates and the three factors mentioned above. Two models have been publicly adopted for use in the U.S. One is EMFAC and the other is MOVES. These two models have various similarities and dissimilarities. APPENDIX B includes reviews of the EMFAC and MOVES models.

2.2.2 Previous air pollution emissions research review

In the 1990s, there were several tests to estimate vehicle emission parameters. Equipment such as data-logger or global positioning system (GPS) was installed to collect data from vehicle operations (Magbuhat, S. and J. Long, 1996; Benjamin, M. and J. Long, 1995). Data were collected to determine distributions of vehicle miles traveled (VMT), trips, temperature, and speed during weekdays and weekends. Grades and other loads effects on emissions were analyzed (Cicero-Fernandez, P. and J. R. Long, 1995, 1996). Benefits on emission rates of on-board diagnostics and inspection/maintenance (I/M) were studied (Patel, D and M. Carlock, 1995). Based on the research results mentioned above, the California Air Resources Board (CARB) developed an air pollution emissions model called EMission FACtors (EMFAC).

Similarly, in the early 2000s, U.S. EPA released several study results. These studies showed how emission rates were estimated for second-by-second vehicle movements (Nam, E. K. 2003; North Carolina State University, 2002). Based on the study results, EPA developed MOVES. Both EMFAC and MOVES provide parameters and necessary input data for passenger cars and trucks. Therefore researchers focused on estimating VMT, which is a primary input data for the two models.

Efforts have been made to estimate VMT more accurately. Four methods have been applied to estimate truck VMT in sub-state areas. First, a travel demand model has been used to estimate VMT from passenger car travels (Hatzopoulou and Miller, 2010). The travel demand model estimates origin-destination flows based on socio-economic data. Then VMT is estimated by applying a trip assignment algorithm on road networks. Truck VMT is calculated by multiplying truck percentage to the estimated total VMT. The method is well developed for personal trips but may not be appropriate for freight trip estimation because of data limitations. Second, diesel fuel sales data has been used to estimate truck VMT (Harley et al., 2004). Since fuel sales data includes passenger vehicle and truck, proportion of truck counts were multiplied with fuel sales data to get truck

VMT. The method can be useful for validating emission inventory in a specific area. But the application would be limited to large urban area.

Third, a top down disaggregation approach has been applied. FHWA developed the Freight Analysis Framework (FAF) database. FAF contains 114 domestic zones and 17 ports of entry for the U.S. Forty-three commodity flows transported by trucks are provided. After the Freight Analysis Framework (FAF) data were released, efforts have been made to disaggregate the state level flows into sub-state areas (Anderson et al., 2008, 2009; Rowinski et al, 2008; Opie et al., 2002; Viswanathan et al., 2008; Harris et al., 2009). Then, assignment algorithms were applied to estimate VMT, based on disaggregated flows.

Fourth, the traffic counts method has been widely used and may be the most common approach to forecast VMT. Truck counts are collected at sample roads. Truck VMT is calculated by multiplying average annual daily truck traffic (AADTT) to the length of roads or multiplying total VMT to the average truck percentage. Sub-regional estimates are obtained by applying extrapolation. Historical traffic count data are used to calculate growth factor and the growth factor is applied to estimate future VMT. The method is efficient and appropriate for statewide estimation but it has limited capacity at the sub-state level.

The four methods have limited capability for sub-state truck VMT estimation. This is because of lack of data. Recently however, the IMPLAN input-output data at ZIP code have been released. IMPLAN provides commodity flows for ZIP codes. We can now obtain truck flows among ZIP code areas by applying a gravity model (Alam et al., 2007). Truck flows indirectly estimated from input-output data may not reflect real truck flows on roads. The problem can be adjusted by comparing the estimated truck flows with observed truck counts on sample areas. Therefore we propose a new approach to obtain VMT based on commodity flows and traffic counts.

3. METHODS APPLIED IN THIS STUDY

This research combines an economic model, a highway network model and an air pollution emissions model. For California, EMFAC 2007 provides vehicle population and VMT data. However, the data do not provide origin-destination flows so that opportunities for policy analysis based on transportation network performance are limited. Freight flows information can be an alternative basis for estimating VMT in local areas (Alam et al., 2007). Several steps are needed to estimate sub-state freight flows from IMPLAN ZIP code area input-output data.

3.1 Origin-Destination (OD) flows estimation

Estimating truck OD flows at the sub-state level is the first step for estimating truck VMT. IMPLAN 2008 ZIP code level data are the basis for estimating truck OD flows among ZIP code areas in California and between California and other States. Figure 3-1 shows the necessary steps.

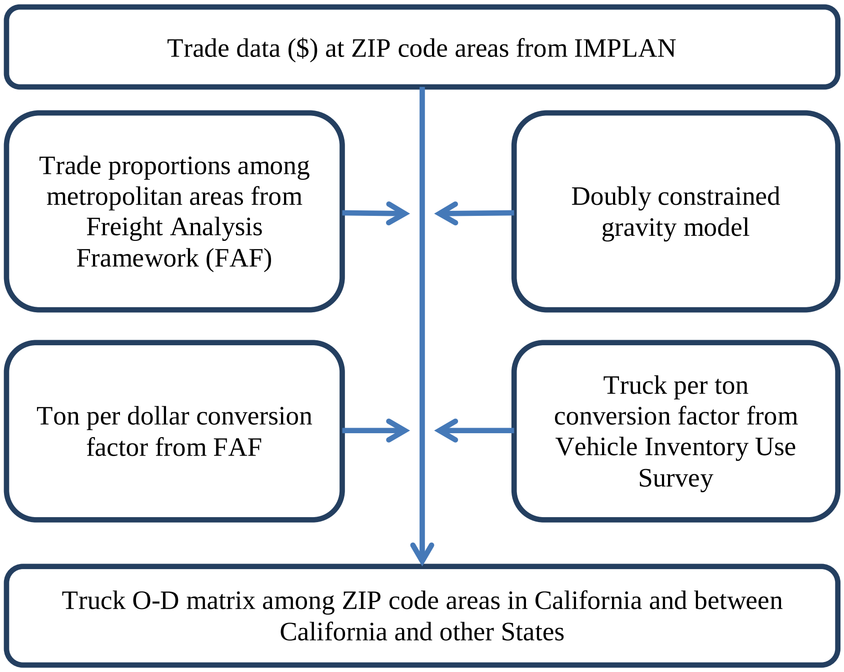


Figure 3-1: Truck OD estimation

IMPLAN data provide commodity outputs and demands in an area. The California data, for example, provide the following information:

- Total Commodity Output produced in California and Total Commodity Demand attracted to California.
- Local Supply which shows commodities supplied by producers located in California.
- Foreign Exports and Foreign Imports
- Domestic Exports and Imports.

Similarly IMPLAN ZIP code data provide the following information:

- Total Commodity Output produced in the ZIP code and Total Commodity Demand attracted to the ZIP code.
- Local Supply which shows commodities supplied by producers located in the ZIP code.
- Foreign Exports and Foreign Imports.
- Domestic Exports and Imports.

To estimate trade flows between ZIP code areas, we first combined individual ZIP code data for California to estimate total local supply and domestic commodity flows by the ZIP code areas of California. Then ZIP code data were combined into the four major MSA areas and one “remainder” area made up of other state MSAs, according to the spatial definitions of the Freight Analysis Framework (FAF). The reason that we aggregated ZIP code data into FAF areas is for validation purposes. There are few data sources to validate trade flow estimation. Commodity Flows Survey (CFS) and FAF are two of the few sources. These two use the same definitions of geographic areas. The following are the types of data that we can be obtained from IMPLAN the model at the California and MSA levels:

California

- Total Commodity Output produced in ZIP code areas and Total Commodity Demand attracted to ZIP code areas in California.
- Foreign Exports and Foreign Imports by ZIP code areas in California.

- Local Supply which shows commodities that are produced and consumed at the same ZIP code areas in California.
- Domestic Exports of ZIP code areas and Domestic Imports into ZIP code areas. Domestic trades also include flows between ZIP code areas.

MSA and remainder of MSAs area

- Total Commodity Output produced in ZIP code areas in each MSA area and remainder of MSA areas and Total Commodity Demand attracted to ZIP code areas in each MSA area and remainder of MSAs area.
- Foreign Exports and Foreign Imports by ZIP code areas.
- Local Supply which shows commodities that are produced and consumed in the same ZIP code areas in each MSA area as well as remainder of MSAs area.
- Domestic Exports of ZIP code areas and Domestic Imports into ZIP code areas. Domestic trades also include flows between ZIP code areas.

Table 3-1 shows the aggregated demand in California and Table 3-2 shows the aggregated demand in California for the truck mode. Truck mode proportions obtained from FAF data are applied to get demand for truck mode.

Table 3-1: Estimated commodity demand and trade flows attracted to ZIP code areas of California (2008)

Units: $ Million

SCTG	Total Commodity Demand	Foreign Imports	Local Supply	Domestic Imports
1	2,070	34	664	1,372
2	4,164	69	66	4,029
3	15,232	1,619	3,076	10,536
4	22,496	575	2,683	19,238
5	12,424	1,314	1,138	9,972
6	10,678	201	1,734	8,743
7	58,155	2,193	6,177	49,785
8	12,698	1,608	156	10,933
9	6,853	76	68	6,709
10	39	1	0.34	38
11	703	17	10	676
12	1,185	23	10	1,151
13	1,055	593	3	459
14	1,163	121	48	993
15	2,663	179	1	2,482
16	116,499	58,546	2,075	55,879
17	47,107	1,712	6,580	38,814
18	18,730	681	2,616	15,433
19	18,889	727	2,516	15,645
20	29,532	3,683	2,700	23,149
21	52,516	4,053	10,330	38,133
22	1,164	362	62	740
23	18,133	886	2,087	15,160
24	46,259	4,541	4,443	37,275
25	1,130	1	454	675
26	13,326	2,056	1,579	9,690
27	11,877	1,399	1	10,477
28	4,863	399	57	4,407
29	19,782	1,759	1,213	16,810
30	32,655	16,064	1,245	15,346
31	17,424	1,433	625	15,366
32	27,957	6,910	1,087	19,960
33	29,305	3,149	1,742	24,414
34	53,994	10,086	7,242	36,666
35	224,568	32,317	56,591	135,660
36	60,988	17,921	4,818	38,249
37	19,696	861	3,458	15,376
38	29,064	3,145	5,696	20,223
39	16,328	3,056	2,342	10,930
40	37,361	14,126	9,116	14,119
41	3,006	82	877	2,047
Total	1,103,730	198,582	147,389	757,760

Data: 2008 IMPLAN model

Local Supply= $\sum_{i=1}^{N} Domestic\ Commodity\ Output\ from\ ZIP\ code\ model$

Domestic Imports= Total Commodity Demand- Foreign Imports- Local Supply

Table 3-2: Estimated commodity demand and trade flows attracted to ZIP code areas of California for truck mode (2008)

Units: $ Million

SCTG	Total Commodity Demand	Foreign Imports	Local Supply	Domestic Imports
1	2,058	25	664	1,369
2	3,584	41	66	3,477
3	14,899	1,440	3,076	10,382
4	21,376	396	2,683	18,298
5	12,131	1,217	1,138	9,776
6	10,444	191	1,734	8,519
7	56,062	1,999	6,177	47,885
8	10,990	1,408	156	9,426
9	6,753	61	68	6,625
10	38	1	0.34	37
11	676	13	10	653
12	1,009	20	10	978
13	929	496	3	430
14	1,035	91	48	896
15	1,156	144	1	1,011
16	60,860	32,619	2,075	26,166
17	31,840	1,023	6,580	24,236
18	11,637	362	2,616	8,658
19	12,147	650	2,516	8,981
20	25,474	2,673	2,700	20,102
21	43,471	3,264	10,330	29,877
22	1,042	277	62	702
23	16,723	649	2,087	13,987
24	42,821	4,097	4,443	34,281
25	1,120	1	454	665
26	12,530	1,818	1,579	9,133
27	10,304	1,285	1	9,017
28	4,604	343	57	4,204
29	16,978	1,504	1,213	14,261
30	28,584	14,114	1,245	13,226
31	16,306	1,244	625	14,437
32	24,425	5,807	1,087	17,531
33	26,877	2,745	1,742	22,389
34	50,102	7,591	7,242	35,269
35	182,646	22,493	56,591	103,562
36	55,644	16,726	4,818	34,100
37	13,007	686	3,458	8,862
38	22,757	2,211	5,696	14,850
39	15,701	2,760	2,342	10,598
40	32,026	11,542	9,116	11,368
41	2,973	60	877	2,036
Total	905,739	146,089	147,389	612,261

Data: 2008 IMPLAN model

Although IMPLAN provides foreign imports and exports as well as domestic imports and exports, only aggregate flows are provided. Data for commodity flows between regions are not provided by IMPLAN. Therefore freight flow proportions between MSA regions were estimated from FAF data and applied to the IMPLAN data to estimate freight flows between MSA regions.

FAF data provide commodity flows between MSA and remainder of MSA regions by SCTG commodity sectors. Table 3-3 and Table 3-4 show domestic and foreign imports and domestic/foreign exports that we can obtain from FAF data for the Los Angeles MSA region.

Table 3-3: 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	Los Angeles MSA	Foreign country	Los Angeles MSA	Los Angeles
Sacramento				Sacramento
San Diego				San Diego
San Francisco				San Francisco
Remainder				Remainder
Other States				Other States

Table 3-4: 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	Los Angeles MSA	Los Angeles	Foreign country
	Sacramento		Sacramento	
	San Diego		San Diego	
	San Francisco		San Francisco	
	Remainder		Remainder	
	Other States		Other States	

Figure 3-2 shows the process of estimating domestic trades for the Los Angeles MSA region by applying FAF trade proportions to IMPLAN data. Four steps were involved, as follows:

Step 1:

1) IMPLAN data at ZIP code areas were aggregated to the Los Angeles five-county region. Similar diagrams can be constructed for all other regions in California.

2) Trade flows were provided in dollar values for 440 IMPLAN sectors. IMPLAN Sectors were converted to 43 SCTG Sectors.

3) IMPLAN domestic trades include consumptions at the Los Angeles MSA and shipments to other regions.

4) IMPLAN domestic trades provide flows coming out of each ZIP code area but don’t provide the final destinations.

5) IMPLAN data are not available by shipping mode.

Step 2:

1) Proportions of shipments using truck mode for domestic trades were estimated for the 43 SCTG Sectors.

2) Dollar and ton values were provided for all origin-destination pairs.

3) FAF data provide flows among MSA regions.

4) Similar diagrams can be constructed for all the MSA regions.

5) Even though FAF data provides flows by modes, IMPLAN data were used for estimation because IMPLAN data provides zip code level information.

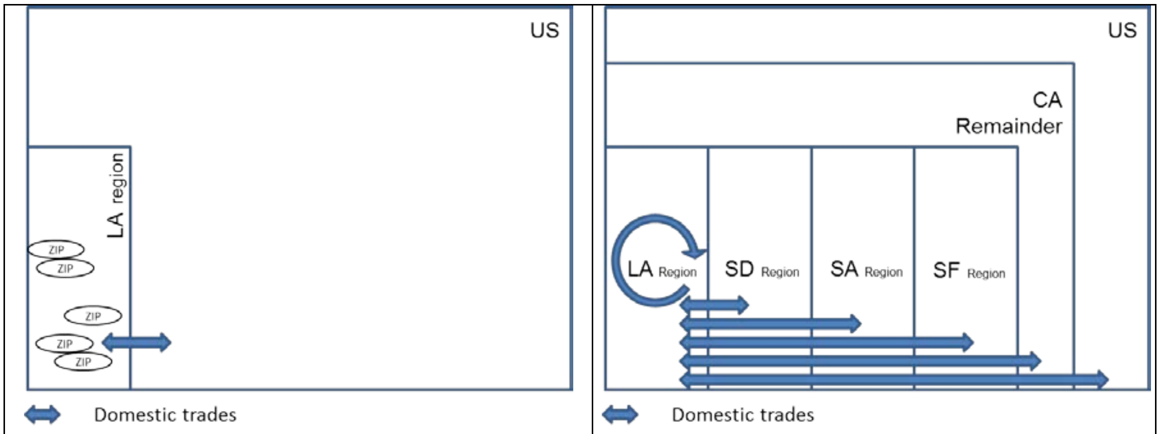
Step 3:

1) Proportions of shipments for truck mode and commodity sectors from FAF data were multiplied to IMPLAN domestic trades.

2) Flows among ZIP code areas were not yet estimated.

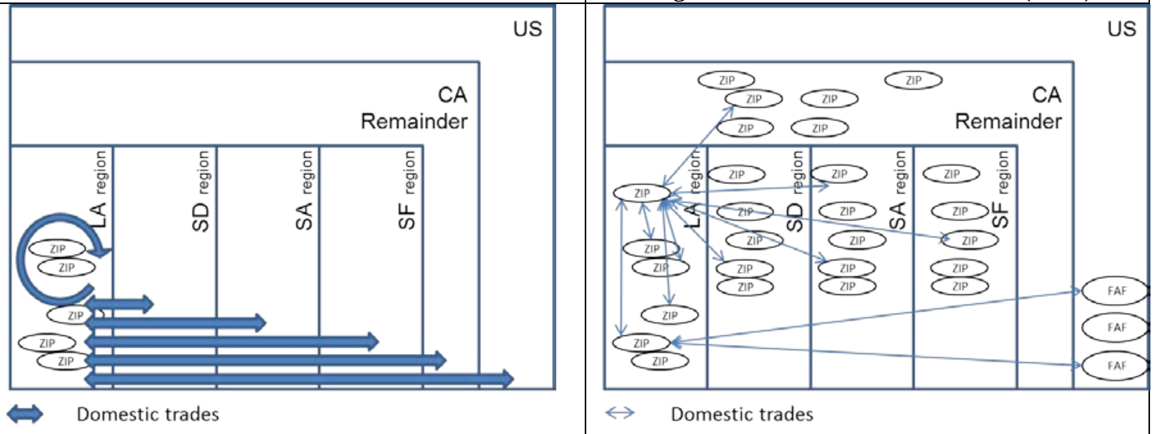
Step 4:

1) Flows among ZIP code areas were estimated by applying a gravity model based on IMPLAN data.



1. Domestic trades from IMPLAN data (2008)

2. : Domestic trades and corresponding domestic origins/destinations from FAF data (2007)



3. Domestic trades from/to Los Angeles MSA region and corresponding domestic destinations/origins by multiplying FAF proportion to IMPLAN data.

4. Domestic trades in Los Angeles MSA region and corresponding domestic origins/destinations of ZIP code areas.

Figure 3-2: Process of estimating domestic trades for the Los Angeles MSA region

Proportions of commodity flows between MSA and the remainder region were estimated based on MSA region data. Appendix Tables 5 and 6 show the estimated proportions for the Los Angeles MSA region. Then the estimated proportions were multiplied by domestic imports and exports of each region. Domestic imports from Table 3-5 are the estimated commodity flows between MSA regions. FAF data also provide mode information for domestic trades. The results for trade flows of the Los Angeles MSA region are shown in Table 3-5, Table 3-6, and Table 3-7.

Table 3-5: Total truck flows originated from California or destined to California at 2030 (Baseline)

Unit: $ Million

SCTG	Total Commodity Demand	Domestic Commodity Output	Foreign Imports							Domestic Imports						
			Total	Destination of shipments after being imported to the						Total	Origin of shipments					
				LA	SA	SD	SF	RE	OS		LA	SA	SD	SF	RE	OS
1	690	21	16	15	0	0	1	0	0	653	371	0	41	0	0	241
2	1,405	1	27	20	1	0	1	0	6	1,377	802	43	176	0	17	339
3	5,168	568	614	343	0	30	33	41	166	3,986	3,111	15	283	55	231	292
4	8,981	865	251	163	0	4	4	2	78	7,865	5,448	0	384	91	194	1,747
5	5,213	260	599	323	0	38	26	1	211	4,354	3,042	1	169	63	262	816
6	4,978	816	93	67	0	1	5	1	19	4,068	2,937	65	95	27	191	752
7	25,447	2,091	944	526	1	18	46	14	339	22,412	14,565	428	320	1,341	1,880	3,878
8	5,045	6	607	349	2	8	44	6	198	4,432	3,758	0	17	143	290	224
9	3,161	19	35	25	0	0	0	0	9	3,106	2,790	0	39	0	83	194
10	17	0	0	0	0	0	0	0	0	16	13	0	0	1	1	1
11	367	7	9	1	0	0	0	0	8	351	318	0	2	6	2	24
12	508	1	10	6	0	0	0	0	4	497	465	1	3	0	20	7
13	451	2	242	91	4	9	27	8	102	207	146	0	4	2	5	50
14	627	15	74	34	0	0	1	0	39	538	28	0	0	0	0	510
15	1,291	1	87	49	0	0	0	0	37	1,203	131	0	2	0	2	1,067
16	40,059	785	20,095	19,077	0	0	962	0	56	19,179	2,828	1,702	2,402	2,762	9,256	228
17	20,654	2,254	777	733	3	5	19	5	12	17,622	16,950	4	20	419	140	90
18	8,212	896	309	136	0	0	171	1	0	7,007	6,196	0	50	264	151	345
19	8,395	971	336	282	0	0	17	1	37	7,089	4,086	0	11	59	87	2,845
20	12,505	1,277	1,620	707	12	36	90	23	752	9,608	4,070	3	107	138	65	5,226
21	25,123	5,002	2,082	1,376	53	92	353	94	113	18,039	12,717	105	50	514	257	4,396
22	334	11	106	15	0	1	2	24	64	217	196	0	1	0	12	7
23	8,744	1,226	403	195	0	8	6	2	192	7,115	4,681	6	73	120	75	2,160
24	23,908	2,930	2,181	948	1	42	25	21	1,144	18,797	13,340	73	417	347	672	3,948
25	216	28	0	0	0	0	0	0	0	188	169	0	2	0	2	15
26	5,997	723	933	379	4	32	17	9	492	4,341	3,174	103	69	43	265	687
27	6,172	1	744	462	0	5	2	1	274	5,427	3,418	0	1	93	67	1,848
28	2,128	28	168	62	1	5	8	3	89	1,932	1,413	1	20	30	63	403
29	9,023	608	816	281	1	16	22	3	493	7,599	4,771	72	142	134	118	2,363
30	17,579	956	7,759	3,718	6	94	352	29	3,559	8,864	5,673	8	322	260	334	2,265
31	7,561	339	601	288	1	7	9	7	289	6,621	5,345	11	242	90	402	531
32	15,917	730	3,676	2,323	8	40	128	43	1,133	11,511	7,767	2	132	440	309	2,860
33	13,990	1,058	1,526	539	2	31	21	9	924	11,407	8,881	28	346	217	418	1,516
34	23,908	2,314	4,975	2,560	3	125	34	31	2,223	16,620	14,258	46	249	71	389	1,605
35	69,769	16,954	10,327	4,831	6	761	499	85	4,145	42,488	21,618	385	3,671	5,982	778	10,054
36	26,092	3,143	7,383	4,189	1	42	92	21	3,037	15,566	10,227	21	1,210	291	171	3,646
37	10,208	2,819	490	225	0	5	36	1	223	6,900	3,640	86	574	18	121	2,460
38	11,847	1,941	1,291	629	0	39	29	4	590	8,615	4,008	46	184	811	43	3,524
39	7,673	1,173	1,422	561	1	32	13	19	796	5,079	3,814	15	59	65	48	1,078
40	15,757	4,162	5,901	3,460	1	108	124	27	2,181	5,693	3,504	19	206	38	167	1,760
41	1,860	520	58	25	0	0	0	0	32	1,282	1,186	0	8	1	41	47
Total	456,978	57,520	79,587	50,013	113	1,637	3,220	534	24,068	319,871	205,855	3,291	12,106	14,936	17,629	66,054

Data: IMPLAN 2008, FAF database 2007(percentage for import distribution),

Note: LA: Los Angeles MSA, SA: Sacramento MSA, SD: San Diego MSA, SF: San Francisco MSA, RE: Remainder of MSA, OS: Other States

Table 3-6: Total truck flows originated from California or destined to California at 2030 (Baseline)

Unit: Thousand Ton

SCTG	Total Commodity Demand	Domestic Commodity Output	Foreign Imports							Domestic Imports						
			Total	Destination of shipments after being imported to the region						Total	Origin of shipments					
				LA	SA	SD	SF	RE	OS		LA	SA	SD	SF	RE	OS
1	681	21	9	8	0	0	1	0	0	651	371	0	41	0	0	239
2	1,185	1	25	19	1	0	1	0	5	1,160	802	43	176	0	17	121
3	5,006	568	533	299	0	27	28	40	138	3,906	3,058	15	282	54	226	272
4	8,467	865	208	132	0	4	4	2	65	7,394	5,448	0	384	91	194	1,276
5	5,055	260	536	318	0	35	26	1	157	4,259	3,019	1	169	63	262	745
6	4,879	816	90	67	0	1	5	1	16	3,973	2,918	61	95	27	191	680
7	24,603	2,091	883	518	1	18	46	13	286	21,629	14,447	409	318	1,305	1,823	3,325
8	3,607	6	461	223	2	8	43	6	180	3,140	2,570	0	17	142	288	124
9	3,133	19	32	23	0	0	0	0	8	3,083	2,782	0	39	0	83	178
10	17	0	0	0	0	0	0	0	0	16	13	0	0	1	1	1
11	351	7	5	1	0	0	0	0	5	339	317	0	2	6	2	13
12	506	1	9	5	0	0	0	0	3	495	465	1	3	0	20	6
13	409	2	212	88	4	9	27	8	76	195	143	0	4	2	5	40
14	595	15	50	20	0	0	1	0	29	530	28	0	0	0	0	502
15	209	1	72	49	0	0	0	0	23	135	131	0	2	0	2	0
16	23,479	785	9,941	1,511	1,045	266	2,860	278	3,981	12,754	39	255	2,142	2,417	7,897	4
17	12,745	2,254	363	334	3	5	18	2	1	10,128	9,685	4	20	240	131	48
18	3,549	896	102	39	0	0	62	1	0	2,550	2,264	0	50	81	151	4
19	5,239	971	270	224	0	0	16	1	29	3,998	3,659	0	11	43	85	199
20	10,364	1,277	1,090	477	10	27	89	20	467	7,998	3,929	3	105	129	65	3,766
21	19,992	5,002	1,664	986	53	92	353	94	85	13,326	9,073	52	45	439	214	3,503
22	324	11	98	14	0	1	2	24	56	215	196	0	1	0	12	5
23	8,129	1,226	309	153	0	6	6	2	143	6,594	4,411	6	62	107	74	1,934
24	22,169	2,930	1,883	909	1	39	24	20	890	17,355	12,731	61	383	324	659	3,196
25	209	28	0	0	0	0	0	0	0	181	169	0	2	0	2	8
26	5,727	723	828	374	4	31	16	9	394	4,175	3,137	103	69	43	254	569
27	5,453	1	685	450	0	5	2	1	227	4,767	3,353	0	1	92	67	1,253
28	2,001	28	138	58	1	5	8	3	64	1,834	1,369	1	20	28	63	353
29	7,848	608	674	258	1	15	21	3	376	6,566	4,360	40	131	125	111	1,799
30	15,267	956	6,623	3,317	6	80	341	27	2,851	7,689	5,134	5	286	200	297	1,767
31	7,242	339	522	281	1	7	9	7	217	6,381	5,205	10	231	87	401	446
32	14,259	730	3,226	2,206	8	37	115	42	818	10,303	7,258	1	126	389	304	2,224
33	12,533	1,058	1,215	492	1	26	19	8	669	10,261	8,087	23	302	184	389	1,275
34	21,899	2,314	3,610	1,700	3	102	31	29	1,745	15,976	13,928	34	244	63	376	1,330
35	57,457	16,954	7,846	3,622	5	557	465	77	3,120	32,658	18,101	218	3,093	3,762	648	6,836
36	23,505	3,143	6,409	3,996	1	37	90	20	2,263	13,953	9,641	19	1,158	274	166	2,696
37	8,058	2,819	355	172	0	5	36	1	142	4,884	2,699	58	478	9	114	1,527
38	9,250	1,941	927	399	0	37	28	4	459	6,383	3,380	23	121	600	40	2,218
39	7,337	1,173	1,240	547	1	32	12	19	628	4,925	3,749	15	58	64	48	992
40	13,302	4,162	4,474	2,705	1	89	119	25	1,535	4,666	3,067	13	149	32	162	1,244
41	1,841	520	49	21	0	0	0	0	27	1,272	1,186	0	8	1	40	38
Total	377,881	57,520	57,663	27,015	1,154	1,603	4,923	788	22,180	262,698	176,322	1,478	10,832	11,424	15,883	46,759

Data: IMPLAN 2008, FAF database 2007(percentage for import distribution),

Note: LA: Los Angeles METRO, SA: Sacramento METRO, SD: San Diego METRO, SF: San Francisco METRO, RE: Remainder of METRO, OS: Other States

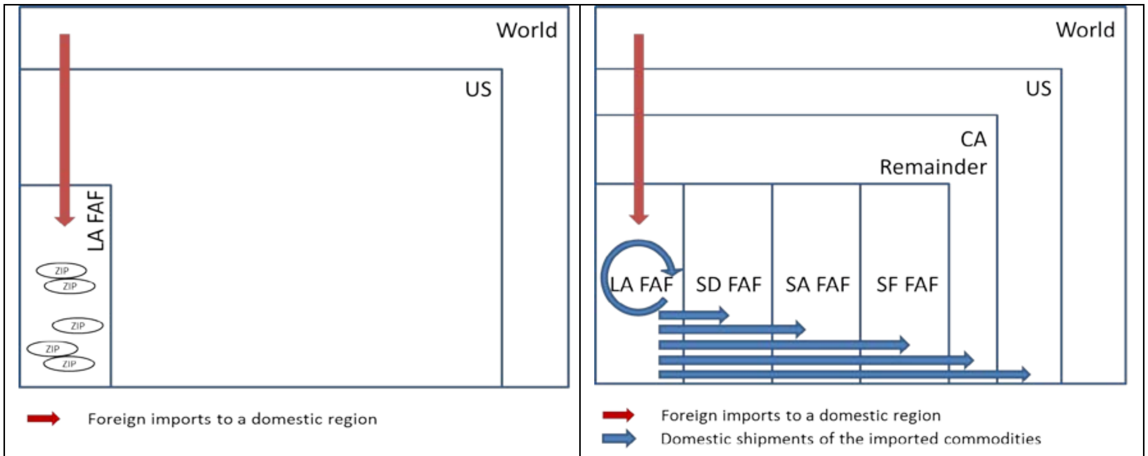
Table 3-10: Total truck flows originated from California or destined to California at 2030 (Baseline)

Unit: Thousand Ton

SCTG	Total Commodity Demand	Domestic Commodity Output	Foreign Imports							Domestic Imports						
			Total	Destination of shipments after being imported to the						Total	Origin of shipments					
				LA	SA	SD	SF	RE	OS		LA	SA	SD	SF	RE	OS
1	281	10	1	1	0	0	0	0	0	270	176	0	4	0	0	90
2	1.174	1	32	24	1	0	1	0	6	1.142	546	93	9	0	73	421
3	5.629	649	588	320	0	38	26	60	145	4.392	3.494	5	331	30	249	283
4	10.683	1.065	125	65	0	3	2	5	49	9.493	6.710	0	386	66	891	1.440
5	1.489	77	130	72	0	13	6	0	40	1.282	899	0	39	8	113	222
6	4.343	724	92	70	0	0	3	1	18	3.526	2.589	102	48	7	121	660
7	24.070	2.215	694	431	1	9	29	12	212	21.161	15.302	236	504	1.448	1.654	2.017
8	2.126	4	262	95	1	5	39	3	118	1.860	1.559	0	11	43	161	86
9	150	1	4	3	0	0	0	0	1	146	135	0	2	0	4	5
10	105	0	11	8	0	0	0	0	2	93	73	0	1	1	15	3
11	21.377	425	119	6	0	0	0	2	111	20.833	20.062	0	124	35	123	489
12	36.063	87	24	16	0	0	0	0	7	35.952	33.991	34	322	0	1.373	231
13	10.030	23	7.993	3.669	371	630	2.463	653	206	2.014	1.815	1	15	11	31	141
14	286	6	236	34	0	0	22	0	179	44	11	0	0	0	0	33
15	4.732	40	588	430	0	3	0	0	154	4.104	3.965	0	71	0	61	7
16	51.631	1,628	21,790	3,134	2,312	588	6,328	614	8,815	28,213	80	564	4,739	5,347	17,473	8
17	15,272	2,675	599	571	3	5	17	2	1	11,999	11,491	7	22	248	154	77
18	5.176	1,299	75	47	3	5	14	5	1	3,802	3,282	0	64	126	324	6
19	12.329	2,260	872	628	0	0	170	2	72	9,197	8,519	0	25	35	418	199
20	17.881	2,657	608	206	11	20	93	22	257	14.616	8.178	3	12	83	173	6.166
21	1.834	623	13	7	0	0	1	0	4	1.199	1.130	0	1	1	4	62
22	1.503	66	194	16	0	1	3	10	163	1.244	1.175	1	10	0	44	14
23	4.582	825	79	29	0	1	2	0	46	3.678	2.968	5	8	81	31	585
24	6.698	813	723	350	0	16	9	7	341	5.161	3.534	21	100	194	162	1.150
25	3.953	555	1	0	0	0	0	0	0	3.397	3.316	0	38	0	33	11
26	6.824	858	619	260	4	21	17	7	310	5,347	3,721	192	56	37	521	819
27	5.600	1	513	315	0	4	1	2	190	5.086	3.239	0	0	150	63	1.634
28	1.288	19	99	46	1	5	11	3	34	1.170	899	1	6	10	72	183
29	2.773	227	208	70	0	6	6	1	125	2.338	1.629	9	69	10	254	367
30	1.562	89	759	381	1	10	37	4	326	715	479	0	6	32	13	184
31	38.636	2.146	802	600	2	7	7	13	172	35.689	32.897	18	414	76	1.763	520
32	8.768	420	2.885	2.095	15	40	128	43	564	5.463	4.181	1	50	434	79	718
33	3.819	321	470	199	0	8	8	3	251	3.029	2.451	1	39	58	229	250
34	2.495	275	383	128	0	11	3	4	236	1.838	1.653	3	32	2	34	114
35	4.010	1,374	615	251	0	39	40	7	277	2,021	1,467	3	68	34	29	420
36	4.967	879	717	413	0	4	13	2	285	3.370	2.697	0	341	27	22	283
37	229	58	26	8	0	0	7	0	10	145	55	54	5	0	1	29
38	1.004	335	33	14	0	2	2	0	15	636	584	0	1	13	0	37
39	1.876	272	547	224	0	15	6	10	291	1.058	869	2	10	17	8	151
40	2.330	849	625	343	0	14	14	4	251	856	625	1	12	2	25	191
41	13.185	3.393	44	22	0	0	1	0	20	9.748	7.742	207	341	643	763	53
Total	342.764	30.241	45.197	15.599	2.730	1.526	9.533	1.502	14.306	267.326	200.187	1.567	8.336	9.311	27.565	20.360

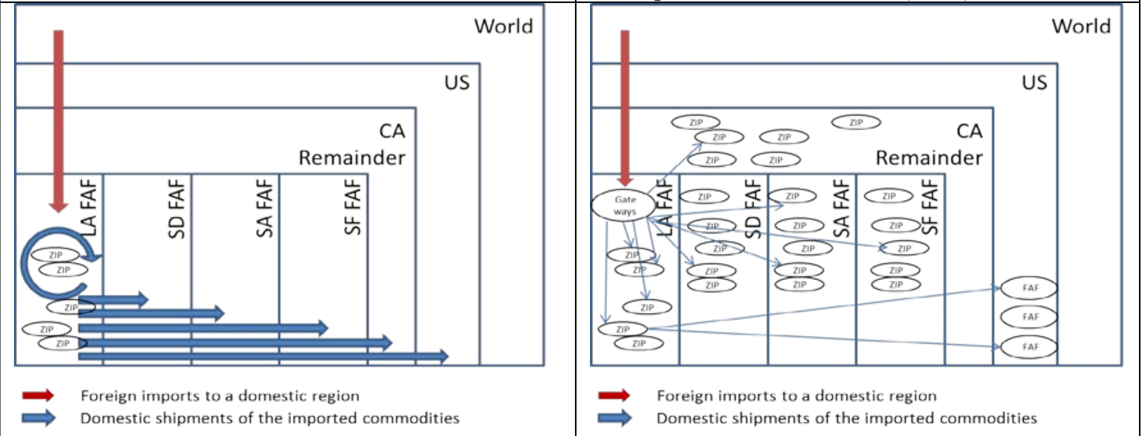
Data: IMPLAN 2008, FAF database 2007(percentage for import distribution and ton-value relations)

Note: LA: Los Angeles METRO, SA: Sacramento METRO, SD: San Diego METRO, SF: San Francisco METRO, RE: Remainder of METRO, OS: Other States



1. Foreign imports from IMPLAN data (2008)

2. Foreign imports and corresponding domestic shipments from FAF data (2007)



3. Foreign imports to Los Angeles FAF region and corresponding domestic shipments by multiplying FAF proportion to IMPLAN data.

4. Foreign imports to gateways in Los Angeles FAF region and corresponding domestic shipments to ZIP code areas.

Figure 3-3: Process of foreign import and corresponding domestic shipment estimation for Los Angeles MSA region

Figures 3-3 and 3-4 show the process of estimating foreign imports and exports and corresponding domestic shipment estimation for the Los Angeles MSA region. Four steps were involved for the estimation, as follows:

Step 1:

1) IMPLAN data for ZIP code areas were aggregated to the Los Angeles five-county region. Similar diagrams can be constructed for all the other regions of California.

2) Imports are provided by dollar values by 440 IMPLAN Sectors. IMPLAN Sectors were converted to 43 SCTG Sectors.

3) IMPLAN foreign imports include consumption at the Los Angeles FAF and shipments to other regions.

4) IMPLAN foreign imports data provide flows coming into each ZIP code area but do not provide the final destinations.

5) IMPLAN data are not available by modes.

Step 2:

1) The flows are provided by different modes (air->truck, water->truck, rail->truck, truck->truck) and 43 SCTG Sectors.

2) Dollar and ton values are provided for all origin-destination pairs.

3) FAF data provide flows among FAF regions.

4) Similar diagrams can be constructed for all the FAF regions.

5) Even though FAF data provides flows by modes, IMPLAN data were used for estimation because we found that IMPLAN is more accurate.

6) FAF mode proportions were calculated and applied to IMPLAN data.

Step 3:

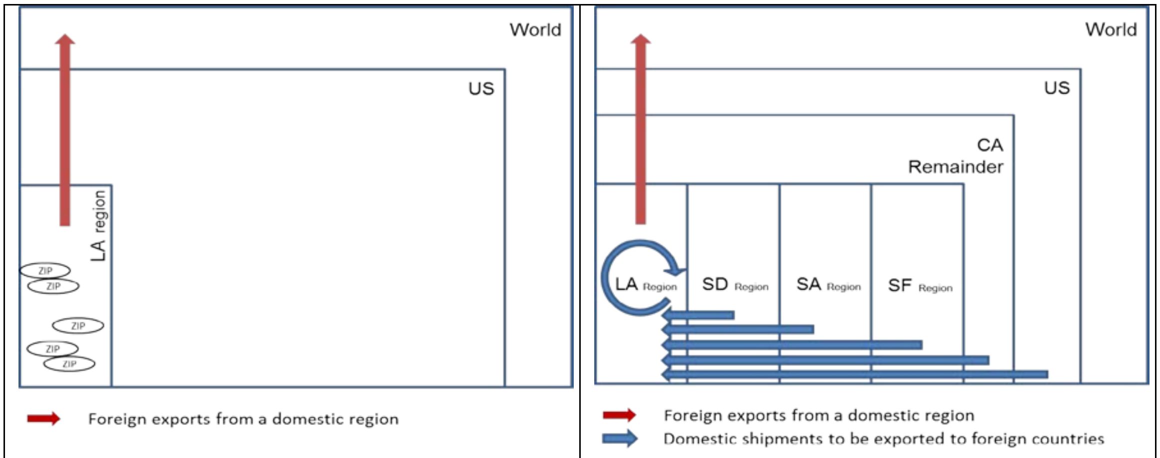
1) Proportions of shipments by modes and commodity sectors from FAF data were multiplied by IMPLAN foreign imports

Step 4:

1) Estimated foreign imports by modes were assigned to the corresponding locations which are designated as gateways (e.g. air mode to airports, water mode to seaports).

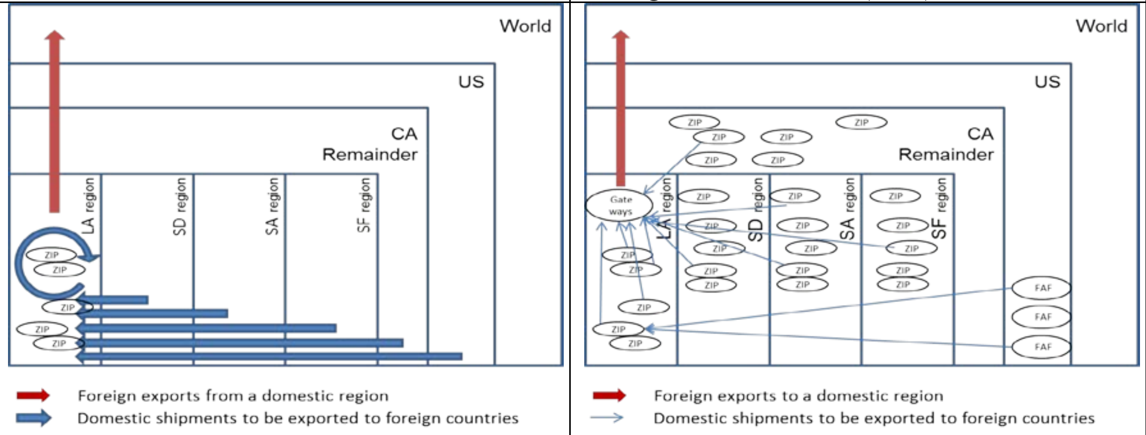
2) Distribution of flows within a mode are based on available statistics (airports: California air cargo statistics (2008), seaports: Waterborne Commerce of the US (WCUS: 2000-2010 by SITC or HS sector) or WISERTrade data)

3) Flows from gateways to ZIP code areas and FAF regions were estimated applying a gravity model based on IMPLAN data.



1. Foreign exports from IMPLAN data (2008)

2. Foreign exports and corresponding domestic origins from FAF data (2007)



3. Foreign exports from Los Angeles FAF region and corresponding domestic origins by multiplying FAF proportion to IMPLAN data.

4. Foreign exports through gateways in Los Angeles FAF region and corresponding domestic origins of ZIP code areas.

Figure 3-4: Process of foreign export and corresponding domestic origin estimation for the Los Angeles MSA region

3.1.1 Foreign import and exports mode split

Foreign imports and exports can involve multiple transport modes such as water-truck, air-truck, and truck-truck. Major regional seaports and airports that handle cargo were selected and the locations of the selected ports were identified.

Modes of shipments for foreign imports/exports

<u>Air ←→ Truck mode</u>

Freight that is imported to California MSAs from foreign countries by air and shipped by trucks to domestic destinations is included in Air (foreign mode) → Truck (domestic mode) mode in the FAF data. Similarly freight that is shipped to California MSAs from domestic origins by trucks and exported to foreign countries by air is included in Truck (domestic mode) → Air (foreign mode) mode in FAF data. Appendix Table 7 shows 2008 California air cargo statistics and the airports selected for this analysis.

<u>Water ←→ Truck mode</u>

Freight that is imported to California MSA from foreign countries by water and shipped by trucks to domestic destinations is included in Water (foreign mode) → Truck (domestic mode) mode in the FAF data. Similarly freight that is shipped to California MSAs from domestic origins by trucks and exported to foreign countries by water is included in Truck (domestic mode) → Water (foreign mode) mode in the FAF data. Appendix Table 8 shows 2008 California seaport cargo statistics and the selected seaports used in this study.

<u>Truck ←→ Truck mode</u>

Freight that is imported to California MSAs from foreign countries by trucks and shipped by trucks to domestic destinations is included in Truck (foreign mode) → Truck (domestic mode) mode in the FAF data. Similarly freight that is shipped to California MSAs from domestic origins by trucks and exported to foreign countries by trucks is included in Truck (domestic mode) → Truck (foreign mode) mode in the FAF data.

Unlike other modes, identifying origin countries of foreign trade would be necessary for the truck mode. These origin locations are either North (Canada) or South (Mexico, Central and South America). We calculated foreign trade proportions between the two foreign locations and each California MSA region by applying the FAF data. Then the calculated proportions were multiplied by MSA level IMPLAN data to estimate foreign trade coming into each California MSA via the truck mode. Flows from the foreign countries to ZIP code areas in each California MSA are estimated by applying a gravity model. Locations of foreign countries are identified at the border regions.

<u>Water ←→ Multi-modes</u>

Freight that is imported into California MSAs through seaports and shipped by rail to domestic destinations were included in flows by water (foreign mode) → multi-modes (domestic mode) in the FAF data[2]. Similarly freight that is exported through seaports in California MSAs and arrives by rail from domestic origins were included in flows of

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[2] When domestic mode is multi-modes, over 99% of them are imported/ exported through seaports in 2007 FAF data.

multi-modes (domestic mode) → water (foreign mode) in the FAF data. Most seaports have rail facilities in port terminals so that freights can be shipped to domestic destinations directly by train. Then the freight that arrives at the rail yards in the destinations is shipped to the ultimate consumers by truck. That is why rail mode traffic is usually expressed via multi-modes.

When imported freight is shipped by train from seaports, the distances from the ports to destinations are usually greater than 500 miles (Port of Los Angeles, 2004: page 9, figure 2-1). So it is unlikely that freight is shipped by train when the destinations are inside California. Similarly when freight is shipped by train to be exported through seaports in California, the origin rail yards are likely located outside California. Therefore we exclude flows of ‘multi-modes’ when we estimate truck flows that are related to foreign trade in California.

3.1.2 Gravity model

After estimating freight flows between MSA regions, we apply a doubly-constrained gravity model to estimate freight flows between ZIP code areas in each MSA region and between MSA regions. A 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. The FAF3 network is used to estimate these shortest paths. (Lindall et al, 2005).

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

Condition1: Sum of all trade flows from a region = that region's total supply.

Condition2: Sum of all trade flows into a region = that region's total demand.

The two conditions are met by iteration. Equation (3) shows how trade flows between regions are estimated.

$$W_{ij} = \left(\frac{D_j \big/ \sum_j D_j}{d_{ij} \big/ \sum_j d_{ij}} \right) \tag{1}$$

$$P_{ij} = \frac{W_{ij}}{\sum_j W_{ij}} \tag{2}$$

$$T_{ij} = O_i P_{ij} \tag{3}$$

Where

W_{ij} is weight values for trade flow from region i to j,

P_{ij}, is gravity factor from region i to j,

T_{ij} is trade flows from region i to j,

O_i is total supply of the commodity originating in region i,

D_j is region js total demand for the commodity, and

d_{ij} is distance between region i and j.

Condition1 (Sum of all trade flows from region i = Total supply of region i) is automatically met because

$$P_i = \sum_j P_{ij} = 1, \quad \sum_j T_{ij} = O_i \sum_j P_{ij} = O_i \text{ for each region i.}$$

To satisfy Condition2 (Sum of all trade flows to region i = Total demand of region i),

D_j region j's total demand is divided by the estimated total inflows, resulting in the following ratio: $B_j = \frac{D_j}{T_j}$.

Then each initial supply-constrained estimate of T_{ij} is multiplied by B_j to obtain the demand-constrained estimate which is $T_{ij}^D = B_j T_{ij} = B_j O_i P_{ij}$.

To satisfy Condition1 (Sum of all trade flows from region i = Total supply of region i) again,

O_i, region i's total supply for the commodity is divided by the estimated total outflows, resulting in following ratio: $A_i = \frac{O_i}{T_i}$.

Each demand-constrained estimate T_{ij}^{D} to origin i is then multiplied by A_i to obtain the second supply-constrained estimates which is $T_{ij}^{S} = A_i T_{ij}^{D} = A_i B_j T_{ij} P_{ij}$.

This iteration is continued until the ratios A_i and B_j are approximately one. The results are balanced trade flows.

FAF data provides dollar and ton values of trade flows between all MSA regions. Dollar values were converted to ton values by applying the dollar-ton relationships from the FAF data. Then trade flows by ton values between ZIP code areas are estimated by applying the gravity model.

VIUS (Vehicle Inventory Use Survey) 2002 data were used to estimate the types of trucks for shipments. Appendix Table 3 shows the percentage by truck types. By multiplying the percentages with the trade flows between ZIP code areas, trade flows between ZIP code areas by truck types are estimated.

Then trade flows data were converted to the number of trucks by applying average payload factors. FHWA provides average payload by vehicle group of Vehicle Inventory Use Survey. Appendix Table 3 show the average payload for California

Truck flows between ZIP code areas by truck types are estimated by dividing the gravity model results with the average payload factors. The estimated truck flows are the Origin-Destination matrix which was used as an input for the transportation impact model to estimate Vehicle Miles Traveled (VMT) on each link of the network.

3.2 Transportation impact model

The User Equilibrium (UE) model is applied to estimate a VMT baseline and to estimate effects of various scenarios. Figure 3-8 shows the procedures used to estimate VMT based on the estimated truck OD matrix.

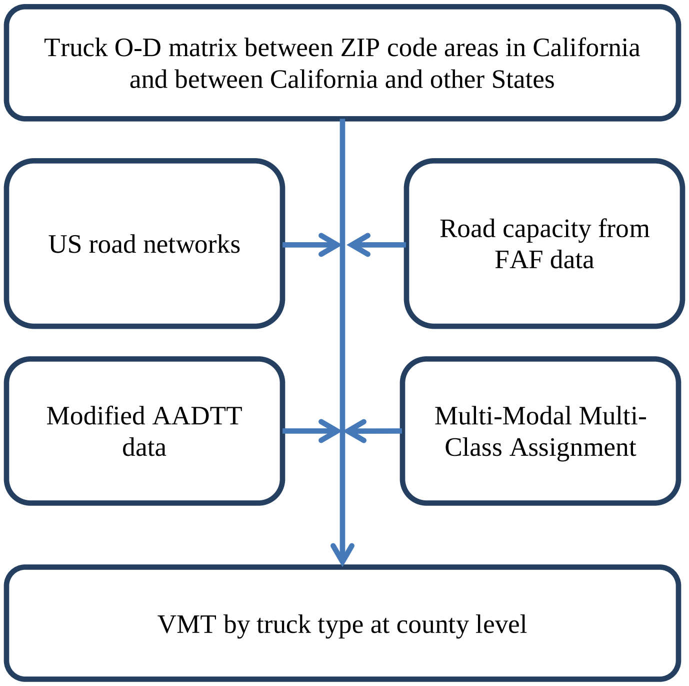

Figure 3-5: Procedures to estimate VMT based on the estimated truck OD matrix

User Equilibrium (UE) assignment model

A UE assignment model is applied for assigning truck flows on road networks. Sheffi (1985) introduced user equilibrium as follows:

$$\text{Min} \quad z(x) = \sum_a \int_0^{x_a} t_a(\omega)d\omega \tag{4}$$

$$\text{subject to} \quad x_a = \sum_o \sum_d \sum_k \delta_{a,k}^{od} f_k^{od} \quad \forall a \tag{5}$$

$$\sum_k f_k^{od} = q_{od} \qquad \forall o, d \qquad (6)$$

$$f_k^{od} \geq 0 \qquad \forall k, o, d \qquad (7)$$

where x_a is the total flow on link a,

$t_a(\omega)$ is the link cost-performance function,

$\delta_{a,k}^{od}$ is the incidence relationship variable; equal to one if link *a* belongs to path k connecting OD pair o and d,

f_k^{od} is flow on path *k* connecting origin *o* with destination *d*,

q_{od} is total trip between origin node *o* and destination node *d*,

The link performance function is shown as follows:

$$t_a = t_a(0)[1 + \alpha(\frac{x_a}{C_a})^{\beta}] \qquad (8)$$

where $t_a(x)$ is the performance function to calculate average travel cost on link *a*, and

$t_a(0)$ is the free-flow travel cost on link *a*,

x_a is the total flow on link *a*,

C_a is the capacity of link *a*,

Historically α and β have been set as 0.15 and 4, respectively. However, different values may be applied according to simulation scenarios (Caliper, 2004).

The equilibrium model can be implemented in the following steps,

Step 0: *Initialization*. Perform all-or-nothing assignment based on $t_a = t_a(0)$ which means there is no congestion. This step yields Link flows x_a^1.

Step 1: *Update*. $t_a^n = t_a(x_a^n)$, $\forall a$.

Step 2: *Find direction*. Perform all-or-nothing assignment based on t_a^n, which yields a set of auxiliary flows { y_a }.

Step 3: *Line search*. Find α_n that solves

$$\min_{0\le\alpha\le1} \sum_a \int_0^{x_a^n+\alpha(y_a^n-x_a^n)} t_a(\omega)d\omega$$

Step 4: *Move*. Set $x^{n+1}_a = x_a^n + \alpha_n(y_a^n - x_a^n)$, $\forall a$

Step 5: *Convergence test*. If a convergence criterion is met, stop (current solution, $\left\{x^{n+1}_a\right\}$, is the set of equilibrium link flows); otherwise, set n:=n+1 and go to step 1.

The estimated VMTs are then used as inputs for the emissions model.

3.3 Air pollution emissions model

Air pollution emissions are estimated by applying an EMFAC model. Figure 3-6 shows the procedures to estimate air pollution emissions based on the estimated VMT by truck type.

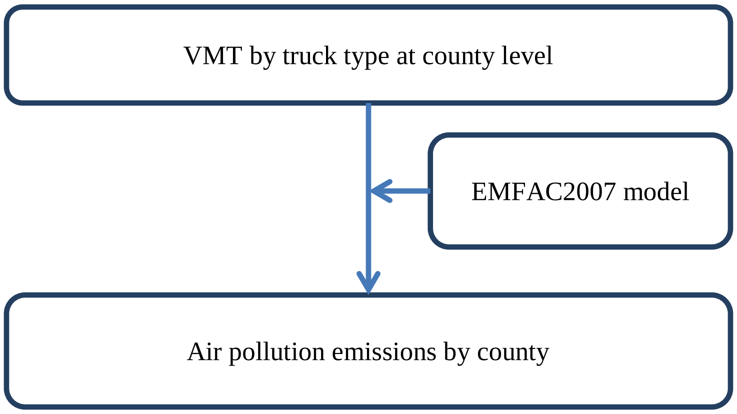

Figure 3-6: Procedures to estimate air pollution emissions based on the estimated VMT by truck type

To estimate air pollution emissions, base emission rates were first adjusted by area specific data such as Inspection and Maintenance (I/M) program, temperature, and relative humidity. Then total emission inventories were estimated by multiplying the adjusted emission rates with total vehicle activity. These adjustments and estimations were accomplised by applying EMFAC model.

4. SCENARIOS

The model developed for this research includes an origin-destination (OD) matrix 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 were identified. The model includes road and highway networks that trucks utilize when traveling between OD 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. In the discussion below, scenario results are compared to projected baseline trends.

The model's OD matrix, however, is not yet differentiated by time of day such as AM peak, PM peak, and off peak. And the model does not include passenger flows. Therefore congestion effects cannot be fully analyzed although the user equilibrium algorithm includes a congestion function.

Baseline: Future growth of foreign trade in SPB

This is the reference case that was used to compare and evaluate the various scenario results. The baseline shows network and emission 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 4-1 shows projected growth at San Pedro Bay which includes the Port of Los Angeles and the Port of Long Beach. To compare the results with other scenarios, we began with a simple projected growth path to 2030. Growth rates from 2008 to 2030 are multiplied by 2008 data for foreign trade via the seaports of Los Angeles County. These results show how the expected growth of trade via the ports affects commodity flows and air pollution emissions.

Table 4-1: Port of Los Angeles and Port of Long Beach throughput demand forecast (baseline)

	Actuals						Forecast			
000 TEU	2000	2005	2006	2007	2008	2009	2015	2020	2025	2030
Import Loads Actual/Forecast TEU	4,949	7,146	8,128	8,115	7,328	6,349	9,182	12,095	15,575	19,801
Export Loads Actual/Forecast TEU	2,029	2,338	2,714	3,182	3,470	3,013	3,942	4,641	5,292	5,938
Outbound Empties Actual/Forecast TEU	2,502	4,499	4,918	4,371	3,540	2,936	4,611	6,559	9,049	12,199
Total TEU	9,480	13,983	15,760	15,668	14,338	12,297	17,735	23,295	29,916	37,938

Source: San Pedro Bay Container Forecast Update (July 2009), available at http://www.portoflosangeles.org/pdf/SPB_Container_Forecast_Update_073109.pdf
Note: CAGR: Compound Annual Growth Rate

Scenario One: Truck replacement scenario- Replacing older trucks with newer trucks

The Clean Truck Program (CTP) at the port of Los Angeles and the port of Long Beach has been successful reducing truck related emissions around the ports[3]. CTP was applied to drayage operations (short haul cargo container trips). For Scenario One, we assumed that a similar program will be applied to all diesel truck in Los Angeles County so that the ages of all diesel trucks would be less than 20 years in 2030 in the County. We take truck populations greater than 20 year of age and shift those to earlier ages based on

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[3] According to the port of Los Angeles (http://www.portofla.org/ctp/idx_ctp.asp), CTP reduced port truck emissions by more than 80 percent in 2012.

current age distributions.

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 of 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[4] as shown in Figure 4-1, we assume that four lanes of eight lanes on I-710 from the ports to SR60 are converted to zero-emission truck lanes by 2030. We also assume that hybrid trucks that which can be operated by electricity and by diesel engine simultaneously are operated on the converted lanes. So 50 percent of the total traffic flows on I-710 from ports to SR60 are converted to zero emission truck flows.

Scenario Three: Land use scenario- Inland port (intermodal facility) at Mira Roma 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 Roma industrial area is one of the candidates for such a development (Rahimi et al., 2008). We assumed that the inland port begins operations in

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[4] http://www.metro.net/projects/i-710-corridor-project/i710-swg-meetings

2030. We found a possible development site from SCAG website as shown in Figure 4-2. 50 percent of truck flows in the port of Los Angeles and the port of Long Beach will be moved from the ports to the inland port for this scenario.

Figure 4-1: I-710 Corridor Project EIR/EIS (Scenario 2; Source: Metro.net)


Possible Development Site at Etiwanda and Iberia

Figure 4-2: Possible development site of inland port at Mira Roma (Scenario 3; Source: SCAG)(Zipcode:91752)

5. MODEL RESULTS

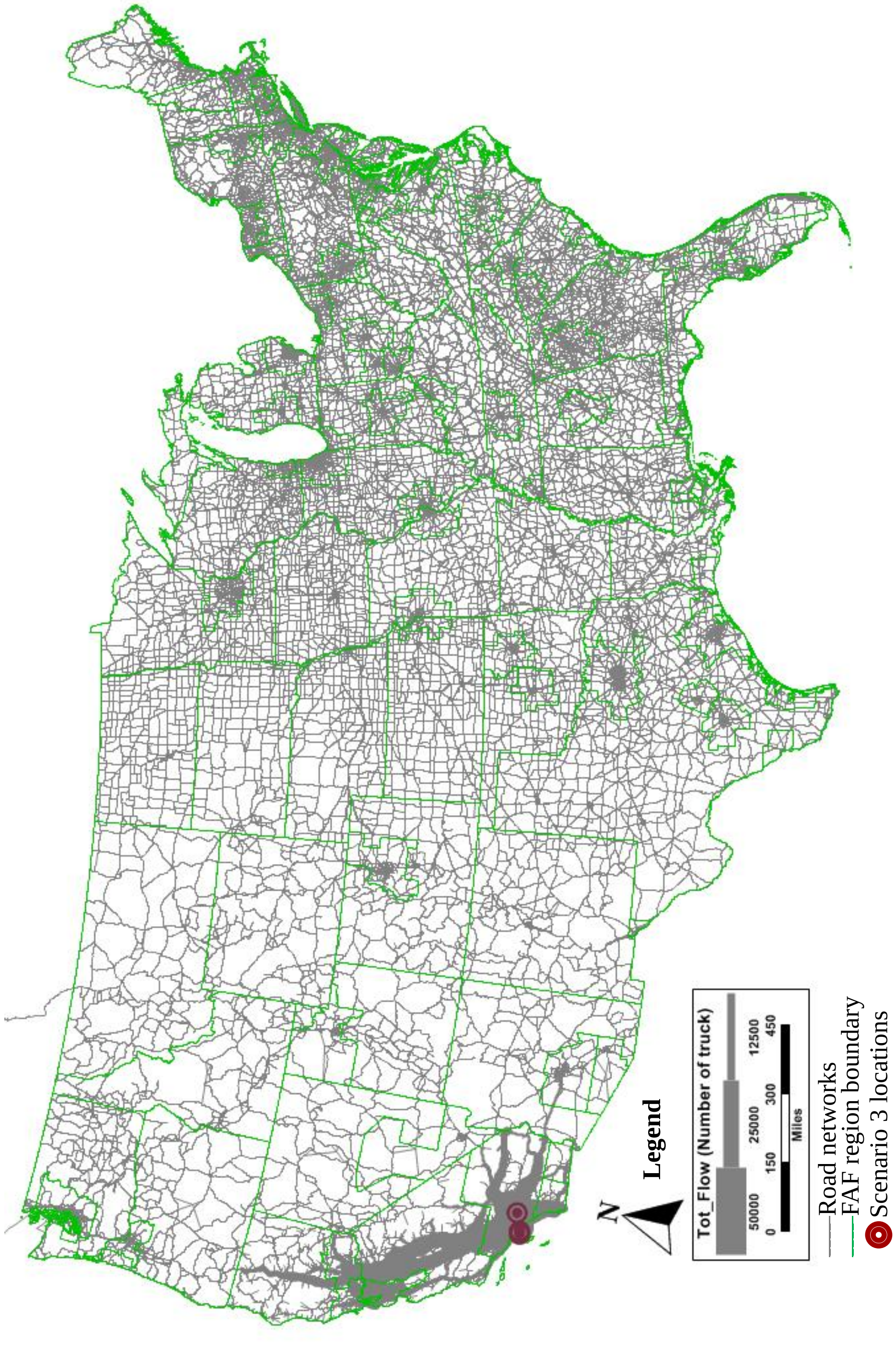

Figure 5-1: Total truck flows originated from California or destined to California at 2030 (Baseline)

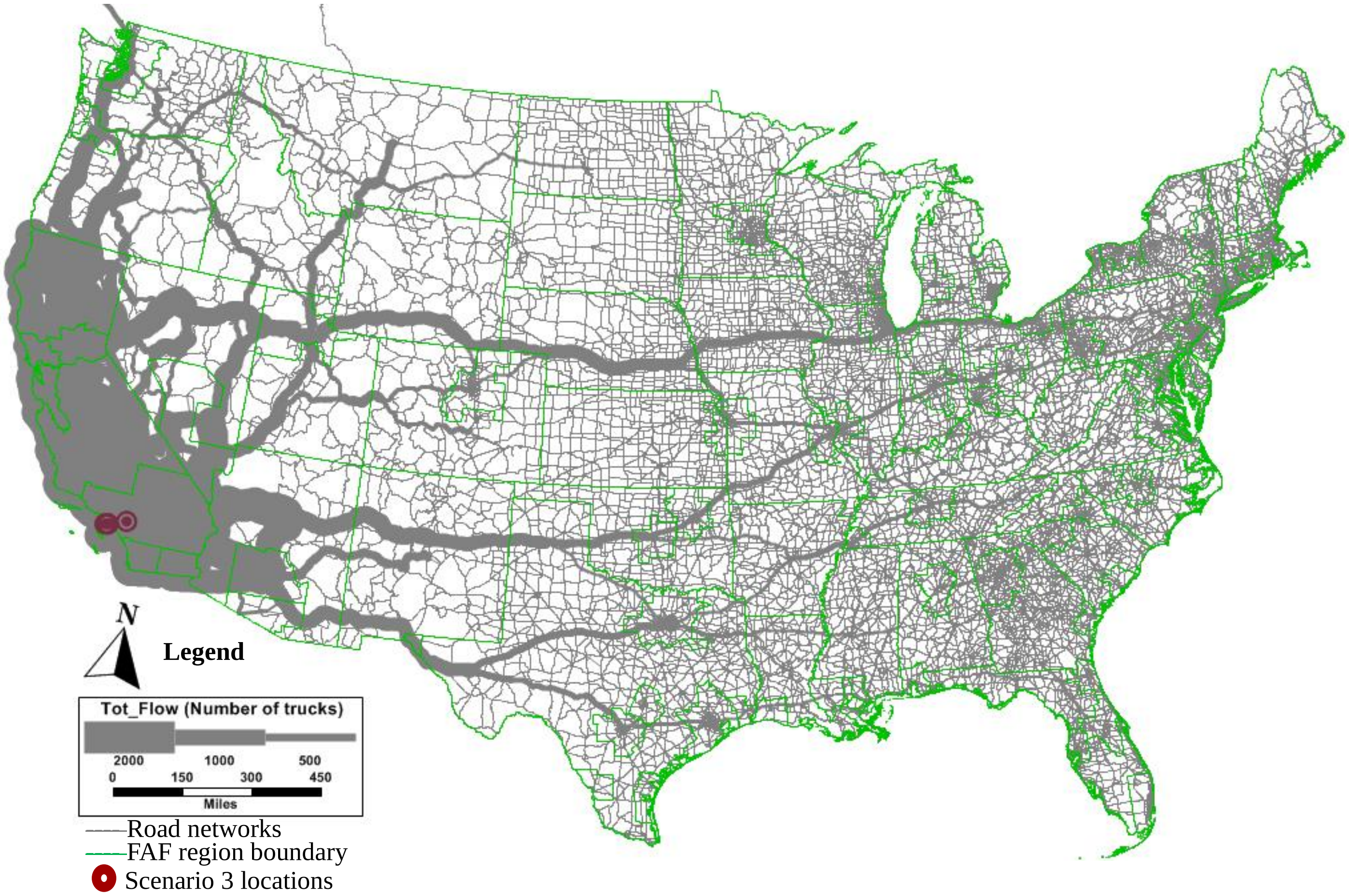

Figure 5-2: Total truck flows originated from California or destined to California at 2030 (to show flows outside CA) (Baseline)

Figure 5-1 shows a simulated total truck flow for the baseline estimates of the model. Because the model only includes truck flows originated from California or destined to California, a relatively high percentage of truck trips occur within California as we see in the figure. Figure 5-2 is a duplicate of figure 5-1 to show flows from California to other states. Note that the label of the total flows in the legend is changed from 50,000, 25,000, 12,500 to 2,000, 1,000, 500 respectively. To estimate the OD matrix applied in the model, 2008 IMPLAN data for ZIP codes were used to estimate initial truck flows between ZIP code areas as explained in Chapter 3. Then truck flows from and to the ports of Los Angeles/Long Beach were modified to reflect 2030 port growth.

These are the steps involved to estimate baseline link volumes:

1) Create IMPLAN-data-based inter zip code (within California) and zip code-to-MSA or MSA-to- zip code (outside California) OD matrix;
2) Estimate 2030 AADTT forecast based on interpolation of their 2007 and 2040 forecasts;
3) Modify derived 2030 AADTT forecast from FAF by applying weights; weights are California originated and destined proportions;
4) Ran user equilibrium model to estimate link volumes for baseline.

5.1 Model results for the Los Angeles MSA

Results for Los Angeles MSA region are explained in this section. To obtain VMT for the MSA region, VMT by vehicle classes for each scenario were aggregated into each county within the MSA. Then the aggregated VMTs were used as inputs for EMFAC model.

Table 5-1 summarizes model results of VMT for the Los Angeles MSA region, including Los Angeles County, Orange County, Riverside County, San Bernardino County, and Ventura County. The Table shows separate results for combined counties based on results of Scenario Three. Los Angeles, Orange, and Ventura counties are combined because the three counties have decrease in VMT for Scenario Three. Riverside and San Bernardino counties are combined because two counties show increase in VMT for the scenario. Note that there is no change in VMT for Scenario One because we assumed that VMT of Scenario One is the same as the one of the baseline. In Scenario Two, VMT for vehicle classes of MHDT and HHDT 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 0.07 percent of reduction.

Table 5-1: 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	0	0	65,143
	MDT		7,990,359	0	0	20,925
	LHDT		2,284,008	0	0	2,301
	MHDT		1,527,658	0	-10,910	2,173
	HHDT		2,308,083	0	-16,407	6,368
	Total	Number	0	0	-27,317	96,910
		%	0.00%	0.00%	-0.07%	0.25%
Los Angeles + Orange + Ventura County	LDT		13,501,956	0	0	-258,623
	MDT		4,500,652	0	0	-86,700
	LHDT		1,285,775	0	0	-27,309
	MHDT		859,145	0	-10,910	-17,353
	HHDT		1,287,066	0	-16,407	-24,388
	Total	Number	0	0	-27,317	-414,373
		%	0.00%	0.00%	-0.13%	-1.93%
Riverside + San Bernardino County	LDT		10,469,120	0	0	323,766
	MDT		3,489,707	0	0	107,625
	LHDT		998,232	0	0	29,610
	MHDT		668,513	0	0	19,526
	HHDT		1,021,016	0	0	30,756
	Total	Number	0	0	0	511,284
		%	0.00%	0.00%	0.00%	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 percent of the truck flows are moved from the ports of Los Angeles/Long Beach to Mira Roma area according to the model results. Total VMT increase is 96,910 miles per day which is 0.25 percent of increase. That result may be because we did not change network attributes around the Mira Roma area. If an inland port is developed in the Mira Roma area, there would be new developments of highways and major arterials to improve network accessibility of the area. Then the network model results may be different than the current results. Even though road networks 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.

This implication is obvious when we compare Figure 5-6 and 5-7. We can see VMT around the ports area has decreased. More explanations will be developed when we compare Los Angeles MSA results with Los Angeles County results later in this chapter.

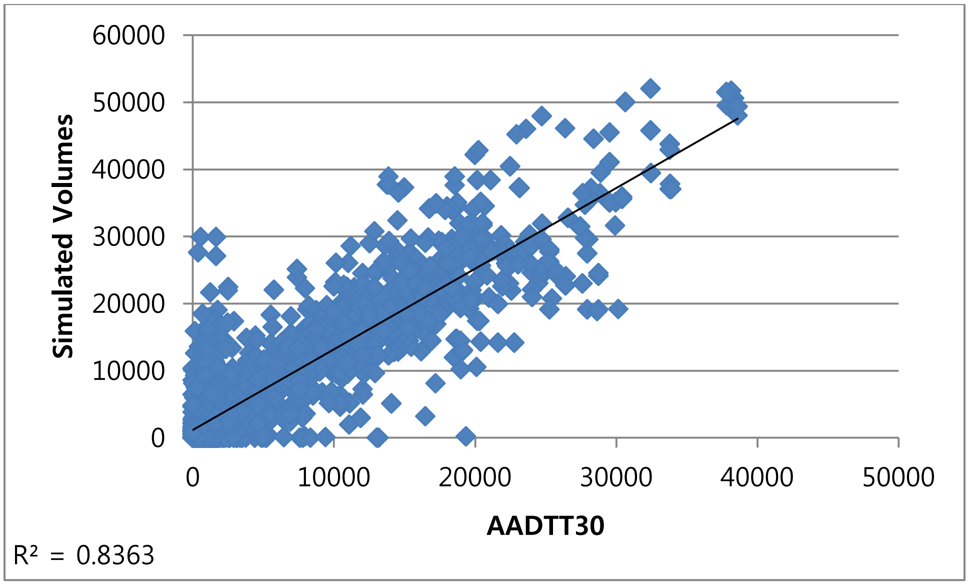

Figure 5-3: Simulated versus Observed (Modified AADTT30) Volumes in Los Angeles MSA

Figure 5-3 displays a scatterplot of simulated and modified AADTT30 for the Los Angeles MSA. When the simulated and observed volumes agree 100 percent, the observations fall on the 45-degree line. The correlation coefficient for model results shows about 84 percent agreement. Table 5-2 shows the comparison of total volumes in the Los Angeles MSA. The difference of total volume of truck between simulated and AADTT30 is about 900,000. In other words, total volumes of the modified AADTT30 and simulated agree over 98 percent.

Table 5-2: Comparison baseline total volumes in Los Angeles County

	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 5-3: Air pollution emissions results for baseline and scenarios in the Los Angeles MSA

Units: tons per day

Baseline								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	5.59	23.14	12.09	5.71	0.96	1.35	2.98	51.82
CO	15.33	69.74	43.16	24.35	4.52	12.24	18.92	188.28
NOx	0.95	5.2	3.04	11.96	2.58	4.55	34.77	63.07
CO2 (1000)	3.76	12.08	7.32	1.81	0.36	2.41	6.12	33.83
PM	0.29	1.51	0.69	0.09	0.01	0.22	0.53	3.34
SOx	0.04	0.11	0.07	0.01	0	0.02	0.06	0.33
Difference from baseline								
Scenario 1								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	-	-	-	-	-	0	-0.02	-0.04
CO	-	-	-	-	-	-0.09	-0.11	-0.21
NOx	-	-	-	-	-	-0.31	-0.23	-0.53
CO2 (1000)	-	-	-	-	-	0	0	0
PM	-	-	-	-	-	-0.01	-0.03	-0.02
SOx	-	-	-	-	-	0	0	0
Scenario 2								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	-	-	-	-	-	0	0	-0.01
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	-0.01
SOx	-	-	-	-	-	0	0	0
Scenario 3								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	0	-0.01	0	0	0	0	0.01	-0.01
CO	0	0.05	0.01	0.01	0	0.01	0.02	0.07
NOx	0	0.01	0.01	0.01	0	0	0.01	0.01
CO2 (1000)	0.01	0.01	0.02	0.01	-0.01	0	0.01	0.06
PM	-0.01	0.01	0	0	0	-0.01	-0.01	0.01
SOx	0	0	0	0	0	0	0	0

Table 5-3 displays the results of air pollution emissions applying the network model results for baseline and three scenarios of the Los Angeles MSA. Note that there are no changes for vehicle classes of LDT1, LDT2, MDV, LHDT1, and LHDT2 in Scenarios One and Two because the two scenarios are only involved in MHDT and HHDT. Scenario One shows the biggest reduction in all pollutants among all the scenarios. Especially NOx 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 displays relatively small changes compared to the other scenarios. Because change in PM is too small compared to the baseline, the results show no change. Scenario Three shows increases in several of the air pollution emissions. PM for all vehicle classes except LDT2 is reduced in Los Angeles MSA although total VMT for the region is increased as shown in Table 5-1. This is because PM reductions in Los Angeles, Orange, and Ventura counties are bigger than 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, we utilized the estimated origin-destination (OD) matrix. We estimated truck proportions originated from Los Angeles County by using the estimated OD matrix. Table 5-4 shows the calculated proportions for the Los Angeles MSA including Los Angeles County, Orange County, Riverside County, San Bernardino County, and Ventura County. Results for Los Angeles County, for example, show that 73 percent 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 percent of the trucks originated from Los Angeles County. Percentages for other Counties can also be interpreted in the same way.

Table 5-4**:** Proportions of trucks originated from the 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 5-5**:** Percent change of air pollution results by applying scenarios in the Los Angeles MSA

Scenario 1

Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	-	-	-	-	-	0.00%	-0.67%	-0.08%
CO	-	-	-	-	-	-0.74%	-0.58%	-0.11%
NOx	-	-	-	-	-	-6.81%	-0.66%	-0.84%
CO2	-	-	-	-	-	0.00%	0.00%	0.00%
PM	-	-	-	-	-	-4.55%	-5.66%	-0.60%
SOx	-	-	-	-	-	0.00%	0.00%	0.00%

Scenario 2

Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	-	-	-	-	-	0.00%	0.00%	-0.02%
CO	-	-	-	-	-	-0.16%	-0.16%	-0.03%
NOx	-	-	-	-	-	-0.44%	-0.14%	-0.11%
CO2	-	-	-	-	-	-0.83%	-0.49%	-0.15%
PM	-	-	-	-	-	0.00%	0.00%	-0.30%
SOx	-	-	-	-	-	0.00%	0.00%	0.00%

Scenario 3

Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	0.00%	-0.04%	0.00%	0.00%	0.00%	0.00%	0.34%	-0.02%
CO	0.00%	0.07%	0.02%	0.04%	0.00%	0.08%	0.11%	0.04%
NOx	0.00%	0.19%	0.33%	0.08%	0.00%	0.00%	0.03%	0.02%
CO2	0.27%	0.08%	0.27%	0.55%	-2.78%	0.00%	0.16%	0.18%
PM	-3.45%	0.66%	0.00%	0.00%	0.00%	-4.55%	-1.89%	0.30%
SOx	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 5-5 displays changes of air pollution emissions in percentage for three scenarios in the Los Angeles MSA. Scenario One shows relatively big impacts than other scenarios. Total change in percentage is also shown by graphs in Figure 5-4.

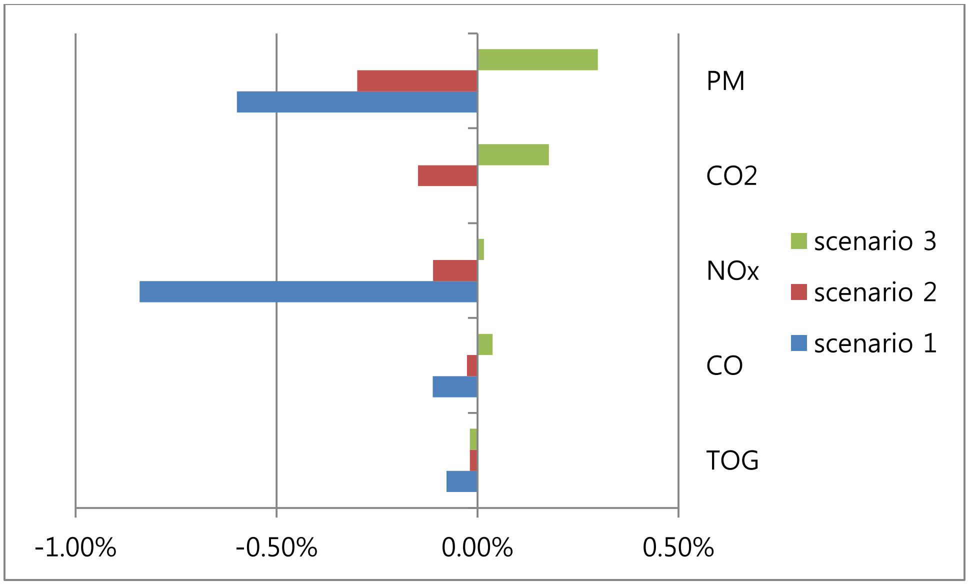

Figure 5-4: Percentage of air pollution emissions reduction for scenarios in the Los Angeles MSA

5.2 Model results for Los Angeles County

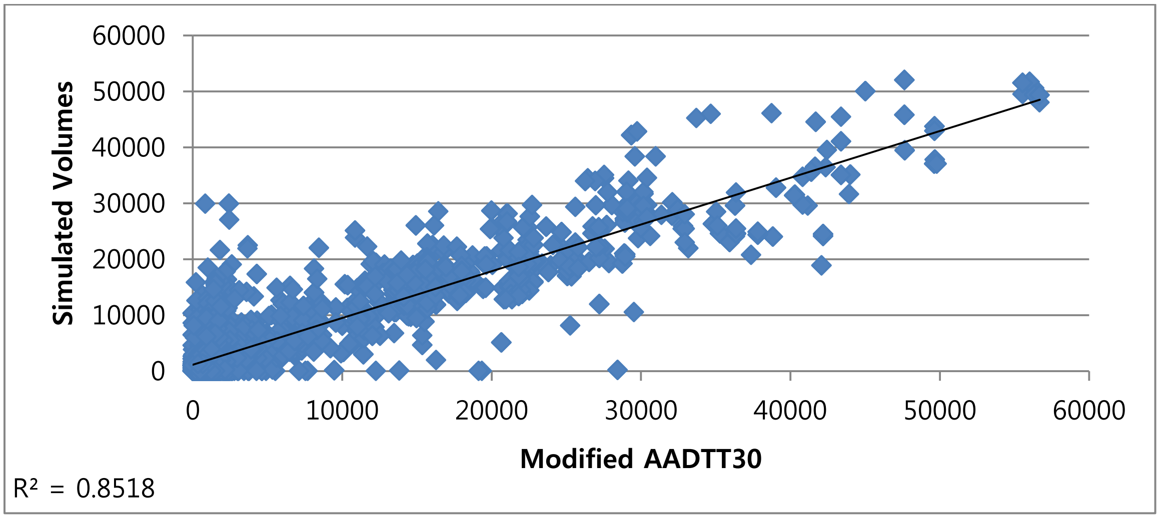

Figure 5-5: Simulated versus Observed (Modified AADTT30) Volumes in Los Angeles County

Figure 5-5 displays a scatterplot of simulated and modified AADTT30 for Los Angeles County. The result is similar to the one for the Los Angeles MSA. The correlation coefficient shows over 85 percent of agreement between simulated volumes and modified AADTT30. Table 5-6 shows the comparison of total volumes in Los Angeles County. Similar to the Los Angeles MSA result, total volumes of the modified AADTT30 and simulated agree by more than 98 percent.

Table 5-6**:** Comparison baseline total volumes in Los Angeles County

	Total volume of truck		Difference (Simulated-AADTT30)	
	Modified AADTT30	Simulated (Base scenario)	Number	%
Volumes	27,753,969	27,803,178	49,208	0.18%

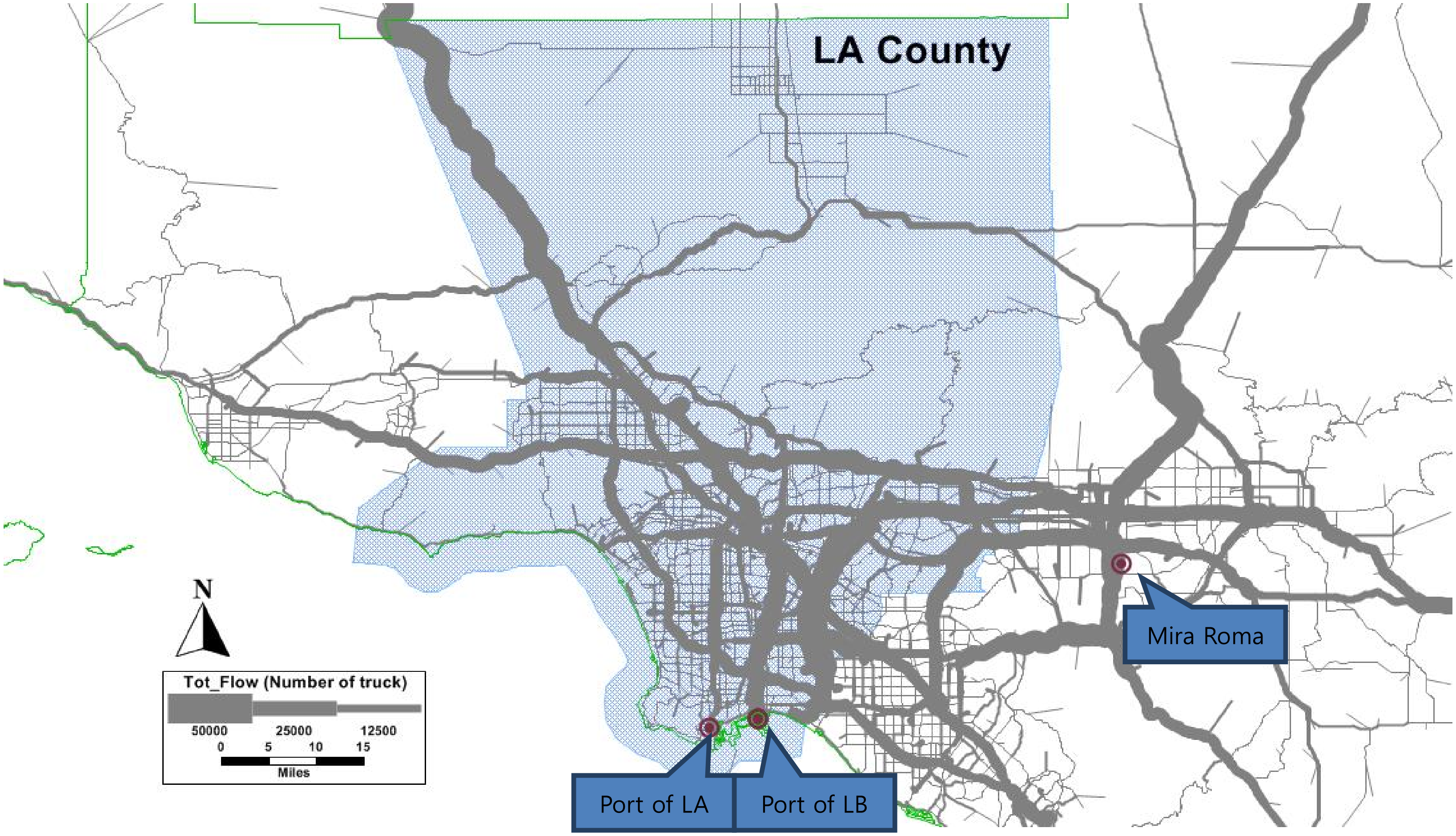

Figure 5-6: Total truck flows around port of LA/LB with port growth at 2030 (Baseline)

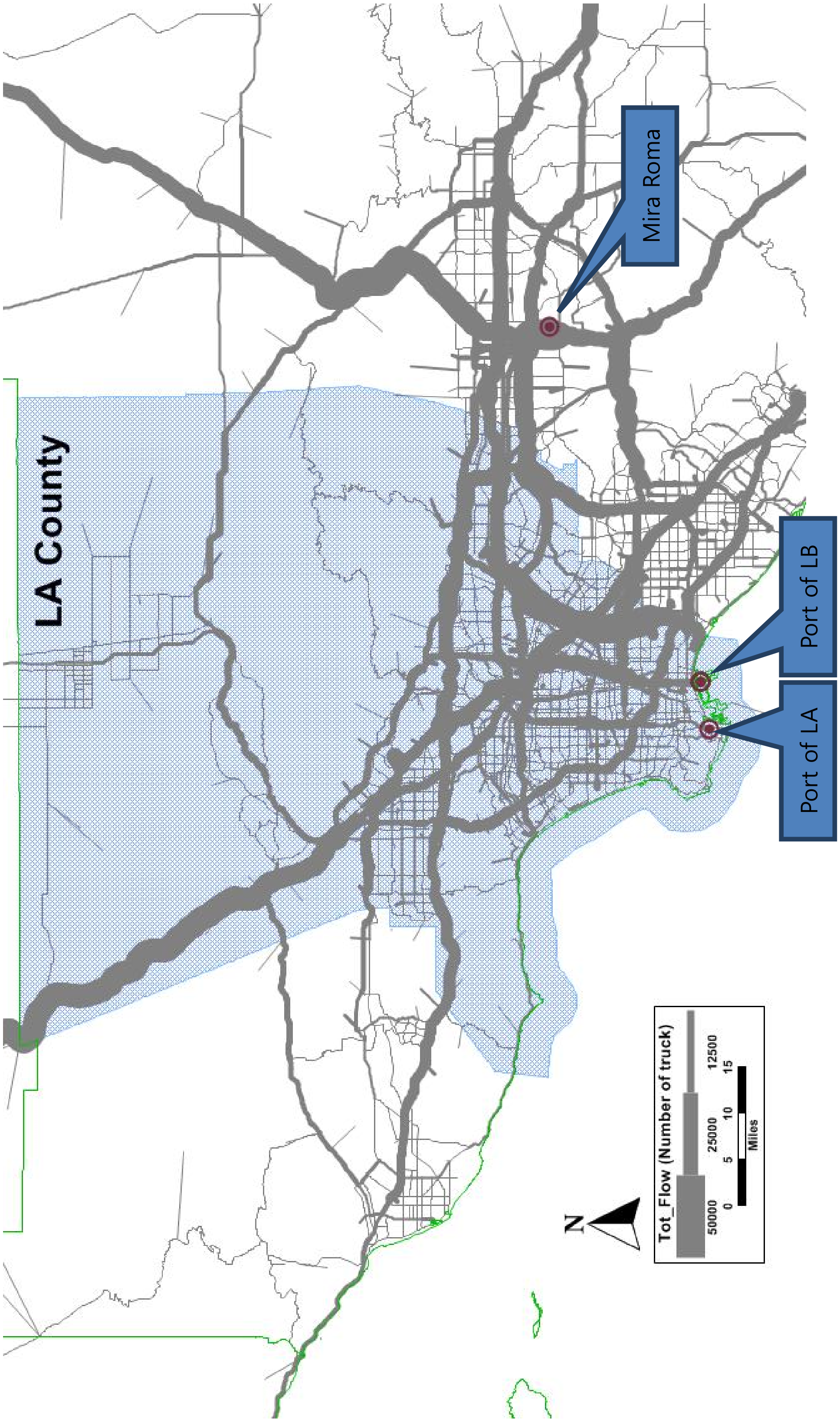

Figure 5-7: Total truck flows around port of LA/LB and Mira Roma (Scenario 3)

Figure 5-6 shows total truck flows around the ports of Los Angeles/Long Beach and Mira Roma for Baseline. Figure 5-7 shows total truck flows around the ports of Los Angeles/Long Beach and Mira Roma for scenario Three. 50% of truck flows are taken from the two ports and are assigned to Mira Roma area. By comparing the two maps we can see that truck flows around the two ports are decreased and flows around the Mira Roma area are increased as a consequence of the scenario.

Table 5-7: Vehicle miles traveled (VMT) in the Los Angeles County

Units: Miles per day

Baseline and Scenarios		Baseline	VMT change from scenario		
			1	2	3
LDT		10,012,255	0	0	-215,567
MDT		3,337,419	0	0	-72,287
LHDT		953,527	0	0	-22,799
MHDT		637,983	0	-10,910	-14,401
HHDT		954,370	0	-16,407	-20,145
Total	Number		0	-27,317	-345,199
	%		0.00%	-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

Table 5-7 shows VMT for the base scenario and VMT changes for the three scenarios. For Scenario One, old trucks are replaced into newer ones but there is no change in VMT because we assumed VMT remains the same. For Scenario Two, VMT of MHDT and HHDT are reduced because we assumed that 50 percent 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, we see a relatively big decrease in VMT when 50 percent of truck flows are moved from the ports of Los Angeles/Long Beach to the Mira Roma area. We can also see that the result is 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 5-1. A part of the reason of the difference is that the Mira Roma area is located in San Bernardino County. Because this table only includes VMT within Los Angeles County, the result shows decreased VMT.

Table 5-8: Air pollution emissions results for baseline and scenarios in Los Angeles County

Units: tons per day

Baseline								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	2.56	11.46	5.67	2.69	0.45	0.7	1.04	24.58
CO	6.85	32.78	19.7	11.91	2.11	6.46	6.57	86.38
NOx	0.42	2.42	1.4	5.59	1.19	2.18	11.09	24.29
CO2 (1000)	1.62	5.32	3.18	0.79	0.16	1.02	2.37	14.45
PM	0.13	0.68	0.3	0.04	0.01	0.1	0.22	1.48
SOx	0.02	0.05	0.03	0.01	0	0.01	0.02	0.14
Difference from baseline								
Scenario One								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	-	-	-	-	-	0	-0.02	-0.03
CO	-	-	-	-	-	-0.07	-0.09	-0.15
NOx	-	-	-	-	-	-0.21	-0.18	-0.38
CO2 (1000)	-	-	-	-	-	0	0	0
PM	-	-	-	-	-	-0.01	-0.01	-0.02
SOx	-	-	-	-	-	0	0	0
Scenario Two								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	-	-	-	-	-	0	0	-0.01
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	-0.01
SOx	-	-	-	-	-	0	0	0
Scenario Three								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	0	-0.01	0	0	0	0	0	-0.02
CO	-0.05	-0.22	-0.12	-0.01	0	-0.02	-0.04	-0.45
NOx	-0.01	-0.02	-0.01	-0.01	0	-0.03	-0.06	-0.13
CO2 (1000)	-0.03	-0.09	-0.05	-0.01	-0.01	-0.02	-0.04	-0.25
PM	-0.01	-0.01	0	0	0	-0.01	-0.01	-0.03
SOx	0	0	0	0	0	0	0	0

Table 5-8 displays air pollution emissions results for the baseline and the three scenarios. There are no changes for vehicle classes of LDT1, LDT2, MDV, LHDT1, and LHDT2 in Scenario One and Two because these two Scenarios only involved MHDT and HHDT.

Scenario One shows the biggest reduction in NOx and 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. Although the network model results were produced for smaller local areas, the EMFAC model is not appropriate for emissions estimations of smaller areas than counties.

Table 5-9: Percent change of air pollution results by applying scenarios in Los Angeles County

Scenario One								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	-	-	-	-	-	0.00%	-1.92%	-0.12%
CO	-	-	-	-	-	-1.08%	-1.37%	-0.17%
NOx	-	-	-	-	-	-9.63%	-1.62%	-1.56%
CO2	-	-	-	-	-	0.00%	0.00%	0.00%
PM	-	-	-	-	-	-10.00%	-4.55%	-1.35%
Sox	-	-	-	-	-	0.00%	0.00%	0.00%
Scenario Two								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	-	-	-	-	-	0.00%	0.00%	-0.04%
CO	-	-	-	-	-	-0.31%	-0.46%	-0.06%
NOx	-	-	-	-	-	-0.92%	-0.45%	-0.29%
CO2	-	-	-	-	-	-1.96%	-1.27%	-0.35%
PM	-	-	-	-	-	0.00%	0.00%	-0.68%
Sox	-	-	-	-	-	0.00%	0.00%	0.00%
Scenario Three								
Vehicle class	LDT1	LDT2	MDV	LHDT1	LHDT2	MHDT	HHDT	Total
TOG	0.00%	-0.09%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.08%
CO	-0.73%	-0.67%	-0.61%	-0.08%	0.00%	-0.31%	-0.61%	-0.52%
NOx	-2.38%	-0.83%	-0.71%	-0.18%	0.00%	-1.38%	-0.54%	-0.54%
CO2	-1.85%	-1.69%	-1.57%	-1.27%	-6.25%	-1.96%	-1.69%	-1.73%
PM	-7.69%	-1.47%	0.00%	0.00%	0.00%	-10.00%	-4.55%	-2.03%
Sox	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 5-9 displays changes of air pollution emissions in percentage for the three scenarios. Scenario One shows significant reduction of NOx and PM in medium-heavy duty trucks (MHDT) and heavy-heavy duty trucks (HHDT). Total change in percentage is also shown graphically in Figure 5-8.

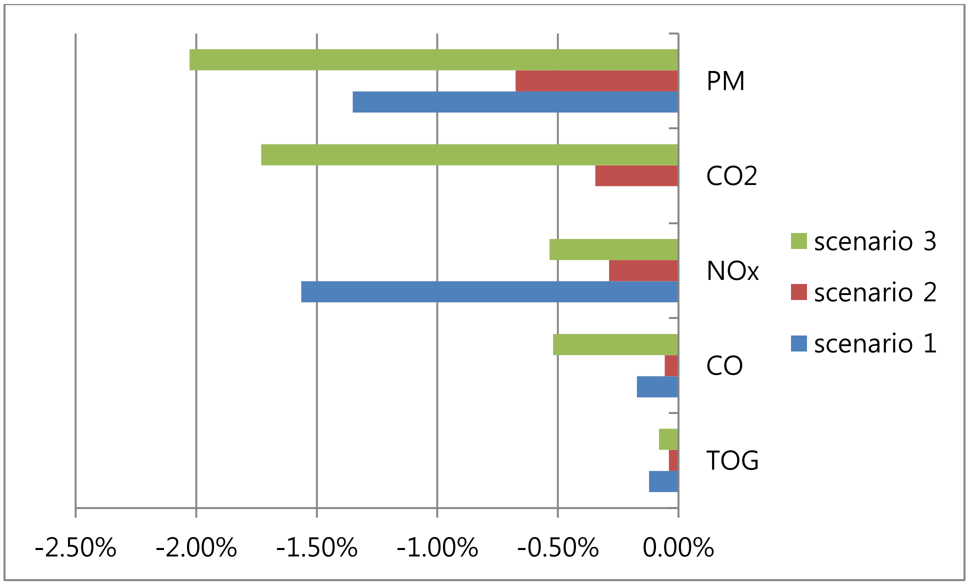

Figure 5-8 Percentage of air pollution emissions reduction for scenarios in Los Angeles County

5.3 Sensitivity analysis

In this section, we explain the results from various sensitivity analyses. We applied three different levels of implementation of each scenario to see how sensitive the model results described in previous pages are.

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 Roma area is selected. Overall, the model performs as expected.

The sensitivity test results show different implications for each scenario;

Scenario One: TOG, CO2, PM SOx are not changed by replacing old trucks because truck populations, VMT, and fuel type are same regardless of the level of implementations. CO and NOx, 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 emission 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 SOx change because of VMT decreases on I-710. But the change is small because the VMT decrease on I-710 is less than 1 percent in 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 SOx are changed because of 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 percent for all of Los Angeles County.

It may seem that the level of policy does not make much difference when we look at the results in Table 5-10 and 5-12. But it does have impacts as we can see in Figures 5-9 and 5-10.

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 truck to 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.

5.3.1 Sensitivity analysis for the Los Angeles MSA

Table 5-10 shows air pollution emissions results for three scenarios for the Los Angeles MSA. Each scenario includes three different levels which are -25 percent, 0 percent, and 25 percent. For Scenario One, -25 percent, 0 percent, and 25 percent mean 50 percent, 75percent, and 100 percent (original scenario) replacement of old trucks into new trucks in Los Angeles County, respectively. For Scenario Two, -25 percent, 0 percent, and 25 percent mean 25 percent, 50 percent (original scenario), and 75 percent reduction of medium-heavy duty truck (MHDT) and heavy-heavy duty truck (HHDT) on I-710 respectively. For Scenario Three, -25 percent, 0 percent, and 25 percent mean 25 percent, 50 percent (original scenario), and 75 percent reduction of truck flows at the port of Los Angeles and Long Beach. It also means 25 percent, 50 percent, and 75 percent increase of truck flows in the Mira Roma area.

In Table 5-10, TOG shows little change for various levels in each scenario. That is because emissions of TOG mostly depend more on vehicle population than VMT. We assumed that numbers of vehicles are 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 levels remain 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 types. 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 are moved from the port of Los Angeles/Long Beach to the Mira Roma area. CO emissions, on the contrary, increased first then decreased when more HHDT flows are relocated.

Table 5-10: 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

Note: For scenario 1, -25%, 0, 25% mean 50 percent, 75 percent, 100 percent replacement of old trucks in the Los Angeles county respectively.

For scenario 2, -25%, 0, 25% mean 25 percent, 50 percent, 75 percent reduction of MHDT and HHDT on I-710 respectively.

For scenario 3, -25%, 0, 25% mean 25 percent, 50 percent, 75 percent reduction of truck flows at the port of Los Angeles and Long Beach.

Table 5-11: Results of sensitivity analysis for the Los Angeles MSA (percent change)

		MHDT		HHDT		Total	
		-25%	25%	-25%	25%	-25%	25%
TOG	Scenario1	0.00%	0.00%	0.34%	0.00%	0.02%	0.00%
	Scenario2	0.00%	0.00%	0.00%	-0.34%	0.02%	0.00%
	Scenario3	0.00%	0.00%	0.00%	-0.33%	0.02%	0.00%
CO	Scenario1	0.16%	-0.25%	0.21%	-0.11%	0.02%	-0.03%
	Scenario2	0.08%	-0.08%	0.05%	-0.11%	0.01%	-0.01%
	Scenario3	-0.08%	0.00%	-0.11%	-0.11%	-0.03%	-0.01%
NOx	Scenario1	1.85%	-1.85%	0.17%	-0.17%	0.24%	-0.19%
	Scenario2	0.22%	-0.22%	0.06%	-0.09%	0.06%	-0.05%
	Scenario3	0.00%	0.00%	0.00%	-0.03%	-0.02%	0.02%
CO2	Scenario1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Scenario2	0.42%	-0.42%	0.33%	-0.33%	0.09%	-0.06%
	Scenario3	-0.41%	0.00%	0.00%	0.00%	-0.12%	0.00%
PM	Scenario1	0.00%	0.00%	2.00%	0.00%	0.00%	0.00%
	Scenario2	0.00%	-4.55%	0.00%	-1.89%	0.00%	0.00%
	Scenario3	4.76%	0.00%	1.92%	0.00%	-0.30%	0.00%

Note: SOx is excluded from the table because emissions are same for all scenarios

In Table 5-11, we calculated the percent changes of -25 percent and 25 percent against the 0 percent level of scenarios. Figure 5-10 is a graphic representation of Table 5-11. CO emissions of MHDT in Scenario One, for example, -25 percent (50 percent old vehicles replacement) show 0.16 percent change which means 0.16 percent more emissions compared to the 0 percent level (75 percent old vehicles replacement) (12.20-12.18)/12.18=0.16 percent). For Scenario One, emissions of CO and NOx are reduced more when more trucks are replaced. CO2 however does not change for the various levels.

For Scenario Two, emissions of all pollutants are reduced when more lanes are converted to zero-emission truck lanes. Scenario Three shows mixed results by levels and pollutants.

Figure 5-9: Results of sensitivity analysis for the Los Angeles MSA (percent change)

5.3.2 Sensitivity analysis for Los Angeles County

Table 5-12 shows results of sensitivity analysis for Los Angeles County. The results of Scenario One and Two are similar to the ones for the Los Angeles MSA. Scenario Three, however, is different from the results for the Los Angeles MSA. Emissions are decreased as more truck flows are moved from the port of Los Angeles/ Long Beach to the Mira Roma area. That would be because the Mira Roma area is located in Riverside County and Table 5-12 include only Los Angeles County. Table 5-13 and Figure 5-10 show percent changes by various levels within each scenario.

Our model enables us to test scenario results of 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. But if and when EMFAC is suitably elaborated to treat smaller areas, our model will be suitably useful. Many policies have effects at the sub-county level and we expect that our model will be useful in analyzing these.

Table 5-12: Results of sensitivity analysis for Los Angeles County

Units: tons per day

		MHDT			HHDT			Total		
		-25%	0%	25%	-25%	0%	25%	-25%	0%	25%
TOG	Scenario1	0.70	0.70	0.70	1.03	1.02	1.02	24.56	24.55	24.55
	Scenario2	0.70	0.70	0.70	1.04	1.04	1.03	24.58	24.57	24.57
	Scenario3	0.70	0.70	0.70	1.04	1.04	1.03	24.57	24.56	24.54
CO	Scenario1	6.42	6.41	6.39	6.53	6.50	6.48	86.30	86.27	86.23
	Scenario2	6.45	6.44	6.43	6.55	6.54	6.52	86.35	86.33	86.31
	Scenario3	6.44	6.44	6.43	6.54	6.53	6.51	86.12	85.93	85.70
NOx	Scenario1	2.07	2.02	1.97	11.00	10.96	10.91	24.10	24.00	23.91
	Scenario2	2.17	2.16	2.15	11.06	11.04	11.01	24.26	24.22	24.19
	Scenario3	2.16	2.15	2.14	11.05	11.03	10.99	24.22	24.16	24.10
CO2	Scenario1	1.02	1.02	1.02	2.37	2.37	2.37	14.45	14.45	14.45
	Scenario2	1.01	1.00	0.99	2.36	2.34	2.32	14.43	14.40	14.38
	Scenario3	1.01	1.00	0.99	2.35	2.33	2.31	14.31	14.20	14.07
PM	Scenario1	0.09	0.09	0.09	0.21	0.21	0.21	1.46	1.46	1.46
	Scenario2	0.10	0.10	0.09	0.22	0.22	0.21	1.47	1.47	1.47
	Scenario3	0.10	0.09	0.09	0.22	0.21	0.21	1.46	1.45	1.44
SOx	Scenario1	0.01	0.01	0.01	0.02	0.02	0.02	0.14	0.14	0.14
	Scenario2	0.01	0.01	0.01	0.02	0.02	0.02	0.14	0.14	0.14
	Scenario3	0.01	0.01	0.01	0.02	0.02	0.02	0.14	0.14	0.14

Note: For scenario 1, -25%, 0, 25% mean 50 percent, 75 percent, 100 percent replacement of old trucks in the Los Angeles county respectively.

For scenario 2, -25%, 0, 25% mean 25 percent, 50 percent, 75 percent reduction of MHDT and HHDT on I-710 respectively.

For scenario 3, -25%, 0, 25% mean 25 percent, 50 percent, 75 percent reduction of truck flows at the port of Los Angeles and Long Beach.

Table 5-13: Results of sensitivity analysis for Los Angeles County (percent change)

		MHDT		HHDT		Total	
		-25%	25%	-25%	25%	-25%	25%
TOG	Scenario1	0.00%	0.00%	0.98%	0.00%	0.04%	0.00%
	Scenario2	0.00%	0.00%	0.00%	-0.96%	0.04%	0.00%
	Scenario3	0.00%	0.00%	0.00%	-0.96%	0.04%	-0.08%
CO	Scenario1	0.16%	-0.31%	0.46%	-0.31%	0.03%	-0.05%
	Scenario2	0.16%	-0.16%	0.15%	-0.31%	0.02%	-0.02%
	Scenario3	0.00%	-0.16%	0.15%	-0.31%	0.22%	-0.27%
NOx	Scenario1	2.48%	-2.48%	0.36%	-0.46%	0.42%	-0.37%
	Scenario2	0.46%	-0.46%	0.18%	-0.27%	0.17%	-0.12%
	Scenario3	0.47%	-0.47%	0.18%	-0.36%	0.25%	-0.25%
CO2	Scenario1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Scenario2	1.00%	-1.00%	0.85%	-0.85%	0.21%	-0.14%
	Scenario3	1.00%	-1.00%	0.86%	-0.86%	0.77%	-0.92%
PM	Scenario1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Scenario2	0.00%	-10.00%	0.00%	-4.55%	0.00%	0.00%
	Scenario3	11.11%	0.00%	4.76%	0.00%	0.69%	-0.69%

CO (MHDT)

CO (HHDT)

CO (Total)

NOx (MHDT)

NOx (HHDT)

NOx (Total)

CO2 (MHDT)

CO2 (HHDT)

CO2 (Total)

PM (MHDT)

PM (HHDT)

PM (Total)

Figure 5-10: Results of sensitivity analysis for Los Angeles County (percent change)

6. 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. We 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 scenarios of reducing air pollution emissions.

The developed model has been applied for evaluating 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 the truck upgrade in Los Angeles County. 2) How much are air pollution emissions reduced by introducing zero emission lanes on I-710 in Los Angeles County, 3) How much are air pollution emissions reduced by developing an inland port at Mira Roma area in Los Angeles County as well as throughout the Los Angeles MSA area.

We 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 may 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 areas.

By analyzing and comparing the results of three scenarios, we have learned various lessons. First, when we consider a policy alternative 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 it can also increase emissions in the county or the 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 an option.

Second, moving transport activities from one site and to another could have both positive and negative impacts. The total air pollution emissions may not be changed although emissions in a local area can be reduced. There are also possibilities to increase overall emissions if proper developments of infrastructure are not implemented. More studies are

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[5] As explained in Chapter 5, the EMFAC model that we applied for estimating air pollution emissions is for county level estimations. Therefore we estimated emissions only at the county level. In Scenario Two, unlike the other two scenarios, emissions reductions occur only on the link of I-710 which is in the scenario area. Therefore we can imagine that if we select only the surrounding area of I-710, the impact of Scenario Two can be significant. The argument becomes clearer when we compare the percent changes of Scenario Two in Tables 5-5 Table 5-9. In Los Angeles County, for example, CO reduction in percentage was 0.03 percent but 0.06 percent in the Los Angeles MSA. Estimating small areas below the county level will be a next step of this research.

needed to estimate land use change strategies thoroughly.

The developed model 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 trip assignment. When both passenger car flows and truck flows are added, the results could be different.

Second, new technologies can change the model results. For the truck replacement scenario, we assumed that old diesel trucks are replaced with newer diesel trucks. Recently however, significant new 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. We could not include natural gas trucks in truck replacement strategy because the EMFAC model does not yet include that fuel category yet. 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 from the Panama Canal expansion can change the model results. The baseline origin-destination truck flows matrix does not take into account the Panama Canal expansion. It is not yet known the extent to which the expansion would be a game changer or if current trends would be continued.

The limitations of the developed model suggest the next steps of the research. Because including passenger vehicles is important to estimate congestion effects, we may consider combining both passenger trips and freight trips in the model. To do that, we may need to change the model area into the study area of local Metropolitan Planning Organizations (MPOs) such as Southern California Association of Government (SCAG) or San Diego Association of Government (SANDAG) to obtain necessary data for passenger trips. We can also update the model when more fuel types such as natural gas are made available in the EMFAC model.

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APPENDIX A: Data for OD estimation

Appendix Table 1: Metropolitan Areas with Component Counties

	Metropolitan Areas	Component Counties	MSA (FAF)
1	Bakersfield	Kern County	69
2	Chico	Butte County	69
		Glenn County	69
		Colusa County	69
		Plums County	69
		Lassen County	69
		Modoc County	69
		Lake County	69
3	El Centro	Imperial County	69
4	Fresno	Fresno County	69
5	Hanford-Corcoran	Kings County	69
6	Los Angeles-Long Beach-Santa Ana	Los Angeles County	61
		Orange County	61
7	Madera	Madera County	69
		Mariposa County	69
		Mono County	69
		Inyo County	69
		Amador County	69
		Alpine County	69
		Calaveras County	69
		Tuolumne County	69
8	Merced	Merced County	69
9	Modesto	Stanislaus County	69
10	Napa	Napa County	64
11	Oxnard-Thousand Oaks-Ventura	Ventura County	61
12	Redding	Shasta County	69
		Trinity County	69
		Siskiyou County	69
		Tehama County	69
		Mendocino County	69
		Humboldt County	69
		Del Norte County	69
13	Riverside-San Bernardino-Ontario	Riverside County	61
		San Bernardino County	61
14	Sacramento--Arden-Arcade—Roseville	El Dorado County	62
		Placer County	62
		Sacramento County	62
		Yolo County	62
		Nevada County	62
15	Salinas	Monterey County	69
16	San Diego-Carlsbad-San Marcos	San Diego County	63
17	San Francisco-Oakland-Fremont	Alameda County	64
		Contra Costa County	64
		Marin County	64
		San Francisco County	64
		San Mateo County	64
18	San Jose-Sunnyvale-Santa Clara	San Benito County	64
		Santa Clara County	64
19	San Luis Obispo-Paso Robles	San Luis Obispo County	69
20	Santa Barbara-Santa Maria	Santa Barbara County	69
21	Santa Cruz-Watsonville	Santa Cruz County	64
22	Santa Rosa-Petaluma	Sonoma County	64
23	Stockton	San Joaquin County	69
24	Vallejo-Fairfield	Solano County	64
25	Visalia-Porterville	Tulare County	69
26	Yuba-Sutter	Sutter County	69
		Yuba County	69
		Sierra County	69

Note:
61: Los Angeles MSA (LA), 62: Sacramento MSA (SA), 63: San Diego MSA (SD), 64: San Francisco MSA (SF), 69: Remainder of MSA (RE)

Appendix Figure 1: California’s 58

Appendix Table 2: SCTG Sector descriptions

SCTG	Context	VIUS
01	Live animals/fish	1
02	Cereal grains	3
03	Other ag prods.	4
04	Animal feed	2
05	Meat/seafood	11
06	Milled grain prods.	10
07	Other foodstuffs	13
08	Alcoholic beverages	9
09	Tobacco prods.	12
10	Building stone	36
11	Natural sands	37
12	Gravel	34
13	Nonmetallic minerals	38
14	Metallic ores	35
15	Coal	32
16	Crude petroleum	33
17	Gasoline	40
18	Fuel oils	39
19	Coal-n.e.c.	42
20	Basic chemicals	5
21	Pharmaceuticals	7
22	Fertilizers	6
23	Chemical prods.	8
24	Plastics/rubber	41
25	Logs	14
26	Wood prods.	18
27	Newsprint/paper	17
28	Paper articles	15
29	Printed prods.	16
30	Textiles/leather	29
31	Nonmetal min. prods.	21
32	Base metals	20
33	Articles-base metal	19
34	Machinery	26
35	Electronics	24
36	Motorized vehicles	30
37	Transport equip.	31
38	Precision instruments	28
39	Furniture	25
40	Misc. mfg. prods.	27
41	Waste/scrap	44

Source: VIUS: US Census Bureau (http://www.census.gov/svsd/www/vius/products.html)
SCTG: U.S. Department of Transportation Bureau of Transportation Statistics (www.bts.gov)

Appendix Table 3: 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	
			LHDT 1	Light-Heavy-Duty Trucks	8501-10000	
Group 3	10,001 to 14,000 lbs.	3,945	LHDT 2	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

Appendix Table 4: Truck use percentages by SCTG Sector

SCTG	LDT1	LDT2	MDT	LHDT1	LHDT2	MHDT	HHDT	TOTAL
1	3%	3%	3%	3%	8%	20%	58%	100%
2	0%	0%	0%	0%	0%	36%	62%	100%
3	2%	2%	2%	2%	4%	26%	62%	100%
4	3%	3%	3%	3%	4%	30%	55%	100%
5	1%	1%	1%	1%	1%	18%	78%	100%
6	3%	3%	3%	3%	10%	34%	44%	100%
7	1%	1%	1%	1%	1%	33%	61%	100%
8	0%	0%	0%	0%	1%	57%	41%	100%
9	1%	1%	1%	1%	1%	12%	82%	100%
10	1%	1%	1%	1%	3%	14%	80%	100%
11	1%	1%	1%	1%	1%	20%	76%	100%
12	0%	0%	0%	0%	1%	13%	84%	100%
13	0%	0%	0%	0%	1%	21%	76%	100%
14	0%	0%	0%	0%	4%	7%	89%	100%
15	0%	0%	0%	0%	1%	3%	94%	100%
16	0%	0%	0%	0%	1%	14%	85%	100%
17	0%	0%	0%	0%		9%	90%	100%
18	1%	1%	1%	1%	2%	47%	48%	100%
19	0%	0%	0%	0%	2%	54%	42%	100%
20	1%	1%	1%	1%	1%	20%	76%	100%
21	6%	6%	6%	6%	4%	28%	43%	100%
22	1%	1%	1%	1%	2%	32%	62%	100%
23	3%	3%	3%	3%	7%	19%	63%	100%
24	2%	2%	2%	2%	7%	22%	63%	100%
25	1%	1%	1%	1%	3%	12%	81%	100%
26	2%	2%	2%	2%	5%	31%	57%	100%
27	1%	1%	1%	1%	1%	13%	83%	100%
28	1%	1%	1%	1%	2%	22%	71%	100%
29	6%	6%	6%	6%	9%	27%	40%	100%
30	3%	3%	3%	3%	7%	29%	50%	100%
31	0%	0%	0%	0%	1%	7%	90%	100%
32	1%	1%	1%	1%	5%	23%	67%	100%
33	4%	4%	4%	4%	8%	28%	47%	100%
34	1%	1%	1%	1%	3%	15%	77%	100%
35	5%	5%	5%	5%	12%	22%	45%	100%
36	3%	3%	3%	3%	6%	35%	47%	100%
37	1%	1%	1%	1%	4%	20%	74%	100%
38	10%	10%	10%	10%	13%	17%	28%	100%
39	2%	2%	2%	2%	7%	21%	64%	100%
40	4%	4%	4%	4%	6%	26%	54%	100%
41	1%	1%	1%	1%	3%	22%	70%	100%

Data: VIUS 2002

Appendix Table 5: Los Angeles MSA import trade proportions

	Percentage of domestic imports by origin					
SCTG	LA	SA	SD	SF	RE	OS
1	0.5684	0.0000	0.0623	0.0000	0.0002	0.3691
2	0.5826	0.0313	0.1279	0.0000	0.0120	0.2463
3	0.7804	0.0037	0.0709	0.0139	0.0579	0.0732
4	0.6927	0.0000	0.0489	0.0115	0.0247	0.2221
5	0.6986	0.0003	0.0389	0.0145	0.0602	0.1875
6	0.7220	0.0161	0.0235	0.0066	0.0470	0.1849
7	0.6499	0.0191	0.0143	0.0598	0.0839	0.1730
8	0.8481	0.0000	0.0037	0.0323	0.0654	0.0505
9	0.8980	0.0000	0.0125	0.0000	0.0268	0.0626
10	0.7877	0.0000	0.0126	0.0872	0.0530	0.0595
11	0.9040	0.0000	0.0048	0.0158	0.0065	0.0690
12	0.9374	0.0028	0.0069	0.0000	0.0398	0.0131
13	0.7028	0.0015	0.0175	0.0117	0.0245	0.2421
14	0.0518	0.0000	0.0007	0.0000	0.0006	0.9470
15	0.1088	0.0000	0.0019	0.0000	0.0017	0.8876
16	0.1475	0.0887	0.1253	0.1440	0.4826	0.0119
17	0.9618	0.0002	0.0012	0.0238	0.0079	0.0051
18	0.8843	0.0000	0.0072	0.0377	0.0215	0.0493
19	0.5764	0.0000	0.0016	0.0084	0.0123	0.4014
20	0.4236	0.0003	0.0111	0.0143	0.0067	0.5440
21	0.7049	0.0058	0.0028	0.0285	0.0143	0.2437
22	0.9039	0.0011	0.0063	0.0012	0.0535	0.0340
23	0.6578	0.0009	0.0102	0.0169	0.0106	0.3036
24	0.7097	0.0039	0.0222	0.0184	0.0357	0.2100
25	0.8986	0.0000	0.0117	0.0000	0.0103	0.0794
26	0.7311	0.0238	0.0158	0.0099	0.0611	0.1583
27	0.6298	0.0000	0.0003	0.0171	0.0124	0.3404
28	0.7316	0.0007	0.0106	0.0155	0.0328	0.2088
29	0.6278	0.0095	0.0187	0.0176	0.0155	0.3110
30	0.6401	0.0009	0.0363	0.0294	0.0377	0.2556
31	0.8073	0.0017	0.0365	0.0136	0.0606	0.0802
32	0.6748	0.0001	0.0115	0.0383	0.0269	0.2485
33	0.7786	0.0024	0.0304	0.0190	0.0366	0.1329
34	0.8579	0.0028	0.0150	0.0043	0.0234	0.0966
35	0.5088	0.0091	0.0864	0.1408	0.0183	0.2366
36	0.6570	0.0013	0.0777	0.0187	0.0110	0.2343
37	0.5276	0.0125	0.0833	0.0026	0.0175	0.3566
38	0.4653	0.0054	0.0214	0.0941	0.0050	0.4090
39	0.7510	0.0029	0.0116	0.0128	0.0095	0.2122
40	0.6155	0.0034	0.0361	0.0066	0.0294	0.3091
41	0.9248	0.0001	0.0059	0.0009	0.0320	0.0363

Data: FAF database 2007

Note: LA: Los Angeles MSA, SA: Sacramento MSA, SD: San Diego MSA, SF: San Francisco MSA, RE: Remainder of MSA, OS: Other States

Appendix Table 6: Los Angeles MSA import trade proportions for truck mode

	Percentage of domestic imports by origin						
SCTG	LA	SA	SD	SF	RE	OS	Total
1	0.5684	0.0000	0.0623	0.0000	0.0002	0.3660	0.9969
2	0.5826	0.0313	0.1279	0.0000	0.0120	0.0881	0.8419
3	0.7671	0.0037	0.0707	0.0134	0.0566	0.0683	0.9799
4	0.6927	0.0000	0.0489	0.0115	0.0247	0.1622	0.9401
5	0.6934	0.0003	0.0389	0.0145	0.0602	0.1710	0.9782
6	0.7174	0.0151	0.0234	0.0066	0.0470	0.1671	0.9766
7	0.6446	0.0183	0.0142	0.0582	0.0814	0.1484	0.9651
8	0.5799	0.0000	0.0037	0.0320	0.0650	0.0280	0.7086
9	0.8957	0.0000	0.0125	0.0000	0.0268	0.0573	0.9924
10	0.7875	0.0000	0.0126	0.0870	0.0530	0.0574	0.9976
11	0.9023	0.0000	0.0048	0.0158	0.0065	0.0364	0.9657
12	0.9356	0.0028	0.0069	0.0000	0.0398	0.0120	0.9971
13	0.6894	0.0015	0.0175	0.0117	0.0245	0.1941	0.9386
14	0.0518	0.0000	0.0007	0.0000	0.0006	0.9319	0.9849
15	0.1088	0.0000	0.0019	0.0000	0.0017	0.0002	0.1126
16	0.0020	0.0133	0.1117	0.1260	0.4118	0.0002	0.6650
17	0.5496	0.0002	0.0012	0.0136	0.0074	0.0027	0.5747
18	0.3231	0.0000	0.0072	0.0116	0.0215	0.0006	0.3640
19	0.5162	0.0000	0.0016	0.0061	0.0120	0.0281	0.5640
20	0.4090	0.0003	0.0109	0.0135	0.0067	0.3920	0.8324
21	0.5029	0.0029	0.0025	0.0243	0.0118	0.1942	0.7388
22	0.9031	0.0011	0.0063	0.0012	0.0535	0.0252	0.9903
23	0.6199	0.0009	0.0086	0.0151	0.0105	0.2719	0.9268
24	0.6773	0.0032	0.0204	0.0173	0.0351	0.1700	0.9233
25	0.8986	0.0000	0.0117	0.0000	0.0103	0.0421	0.9627
26	0.7228	0.0238	0.0158	0.0099	0.0584	0.1312	0.9618
27	0.6178	0.0000	0.0003	0.0170	0.0124	0.2309	0.8784
28	0.7085	0.0007	0.0103	0.0147	0.0327	0.1828	0.9496
29	0.5738	0.0053	0.0173	0.0164	0.0146	0.2368	0.8641
30	0.5792	0.0005	0.0323	0.0225	0.0335	0.1994	0.8675
31	0.7862	0.0016	0.0349	0.0132	0.0606	0.0673	0.9637
32	0.6306	0.0001	0.0110	0.0338	0.0264	0.1932	0.8951
33	0.7090	0.0020	0.0265	0.0162	0.0341	0.1118	0.8995
34	0.8380	0.0021	0.0147	0.0038	0.0226	0.0800	0.9612
35	0.4260	0.0051	0.0728	0.0885	0.0152	0.1609	0.7686
36	0.6193	0.0012	0.0744	0.0176	0.0107	0.1732	0.8964
37	0.3912	0.0084	0.0693	0.0013	0.0165	0.2213	0.7079
38	0.3924	0.0027	0.0141	0.0697	0.0047	0.2574	0.7408
39	0.7382	0.0029	0.0114	0.0126	0.0094	0.1954	0.9698
40	0.5387	0.0022	0.0261	0.0056	0.0284	0.2185	0.8196
41	0.9247	0.0001	0.0059	0.0009	0.0310	0.0296	0.9923
Avg.	0.6150	0.0037	0.0260	0.0201	0.0364	0.1538	0.8550

Data: FAF database 2007

Note: LA: Los Angeles MSA, SA: Sacramento MSA, SD: San Diego MSA, SF: San Francisco MSA, RE: Remainder of MSA, OS: Other States

Appendix Table 7: 2008 California air cargo statistics

Unit: U.S. ton

Airport name	2008 total	FAF region	ZIP	county
Arcata	664.9	69	95519	Humboldt
Bob Hope	42,908.90	61	91505	Los Angeles
Fresno-Yosemite Int'l	9,741.10	69	93727	Fresno
John Wayne	16,829.80	61	92707	Orange
LA Ontario Int'l	481,283.00	61	91761	Los Angeles
Long Beach	44,352.60	61	90808	Los Angeles
Los Angeles Int'l	1,797,780.00	61	90045	Los Angeles
March ARB (Air reserve base)	26,044.20	61	92518	Riverside
Merced Municipal	71.7	69	95341	Merced
Metro Oakland Int'l	679,117.50	61	94621	Alameda
Modesto	312.1	69	95354	Stanislaus
Monterey	618	69	93940	Monterey
Murray Field	6,331.90	69	95501	Humboldt
Palm Springs Int'l	26	61	92262	Riverside
Redding Muni	1,675.90	69	96002	Shasta
Sacramento Int'l	79,319.30	62	95837	Sacramento
Sacramento Mather	77,100.10	62	95655	Sacramento
San Diego Int'l	133,913.10	63	92101	San Diego
San Francisco Int'l	543,197.60	64	94128	San Mateo
San Jose Int'l	81,222.20	64	95110	Santa Clara
San Luis Obispo	1,332.90	69	93401	San Luis Obispo
Santa Barbara Muni	2,797.00	69	93117	Santa Barbara
Sonoma County	672.8	64	95403	Sonoma

Source: California Department of Transportation, 2008 California Air Cargo Statistics (http://www.dot.ca.gov/hq/planning/aeronaut/documents/2008Cargo2009Apr.pdf)

Note: 2008 total includes imports and exports. We selected airports that have more than 100,000 ton at 2008. Selected 5 airports handle more than 90 % of total air cargo.

Appendix Table 8: California sea ports unit: U.S. ton

Seaport name	2008 Import	2008 Export	FAF region	ZIP	county	Main Cargo Types of imports	Main Cargo Types of exports
Benicia			64	94510	Solano		
Hueneme	1,216,595	62,424	61	93044	Ventura	Autos, Produce Liquid Fertilizer Nuts, Bulk Liquid	Autos Produce General Cargo
Humboldt Bay			69	95502	Humboldt	Logs Petroleum	Logs, Wood chips Lumber
Long Beach	45,186,084	22,084,935	61	90802	Los Angeles	Crude oil Electronics Plastics Furniture Clothing	Petroleum coke Petroleum bulk Chemicals Waste Paper Food
Los Angeles	32,732,756	20,180,533	61	90731	Los Angeles	Furniture Automobile parts Apparel Electronic Products Footwear	Wastepaper Scrap Metal Animal Feeds Cotton Resins
Oakland	6,497,039	8,631,041	64	**94607**	Alameda	Furniture Plastic ware, tiles Computers Machinery/parts Machinery	Fruit, Nuts Beverages Meats Machinery Lumber
Redwood City	1,310,112	299,832	64	**94063**	San Mateo	Cement Gypsum Bauxite Sand, Building Aggregates	Scrap Metal Rock Non-ferrous metals
Richmond	13,044,242	2,898,576	64	94804	Contra Costa	break-bulk, bulk, project cargo	chemicals, pharmaceuticals, forest products, machinery, frozen seafood, produce, bottled water from Iceland, recreational campers, steel, steel products, stone, tobacco leaf, aluminum, project cargo, vehicles, recreational boats, wire coils, wire rods, pipe, bulk grain, minerals, and

							livestock
West Sacramento	476,983	347,710	62	95691	Sacramento		
San Diego	1,463,243	16,343	63	92101	San Diego		
San Francisco	803,968	55,539	64	94111	San Francisco	Steel Products Boats / Yachts Wind Turbines Project Cargo Aggregate Sand	Tallow Vegetable Oil
Stockton	1,218,654	513,469	69	95203	San Joaquin	Cement Molasses Steel Products Palm Oil Machinery Boric Acid Lumber Fertilizer Windmills Anhydrous Ammonia	Sulphur Bulk Rice Bagged Rice Machinery Wheat Steel Scrap Petroleum Coke Safflower Seed Iron Ore / Cole

Source: American Association of Port Authorities
(http://aapa.files.cms-plus.com/Statistics/2008%20U.S.%20PORT%20RANKINGS%20BY%20CARGO%20TONNAGE.pdf)
Main Cargo Types : California DOT
(http://www.dot.ca.gov/hq/tpp/offices/ogm/fact_sheets_index.html)
Main cargo types that are not available at California DOT were obtained from port website.
Port of LA: http://www.portoflosangeles.org/about/facts.asp
Port of Richmond: http://www.richmondgov.com/PortOfRichmond/index.aspx
Note: No data is available for Port of Benicia. We selected ports that have more than 10,000,000 tons of trades at 2008. Selected four ports handle over 95% of total cargo.

Appendix Table 9: Foreign Import Mode proportion

SCTG	Air(including air-truck)	Water-Truck	Water-multiple	Truck-Truck	Multiple-truck	Others
1	55.78%	8.42%	0.04%	35.69%	0.01%	0.06%
2	0.48%	17.99%	3.27%	11.85%	0.00%	66.41%
3	4.93%	45.79%	9.31%	38.21%	0.03%	1.73%
4	19.48%	64.17%	13.17%	1.08%	0.03%	2.08%
5	0.31%	77.19%	10.47%	3.20%	0.00%	8.83%
6	0.26%	77.11%	8.36%	12.22%	0.00%	2.04%
7	1.20%	74.06%	12.26%	9.46%	0.01%	3.01%
8	0.55%	63.62%	12.10%	16.18%	0.03%	7.51%
9	11.16%	74.12%	11.34%	2.29%	0.12%	0.98%
10	0.00%	90.33%	8.33%	0.00%	0.00%	1.34%
11	0.00%	24.97%	74.53%	0.00%	0.00%	0.50%
12	0.00%	78.13%	10.58%	0.00%	0.00%	11.28%
13	0.78%	50.82%	36.31%	10.62%	0.02%	1.45%
14	16.53%	60.16%	18.68%	0.00%	0.00%	4.64%
15	0.00%	55.44%	41.07%	0.00%	0.00%	3.49%
16	0.00%	0.00%	0.00%	0.00%	0.00%	100.00
17	0.00%	47.68%	0.04%	0.00%	0.00%	52.28%
18	0.00%	31.34%	8.47%	0.00%	0.00%	60.19%
19	0.58%	89.90%	2.49%	0.00%	0.00%	7.03%
20	27.33%	42.94%	16.34%	0.07%	0.00%	13.32%
21	27.00%	22.78%	5.37%	43.26%	0.06%	1.53%
22	0.05%	42.96%	29.95%	0.05%	0.00%	27.00%
23	29.81%	39.27%	15.92%	6.88%	0.43%	7.68%
24	1.64%	64.00%	26.85%	6.19%	0.35%	0.97%
25	0.00%	73.07%	22.03%	0.00%	0.00%	4.90%
26	0.93%	68.86%	24.34%	4.86%	0.20%	0.82%
27	0.00%	80.37%	16.99%	0.54%	0.00%	2.09%
28	2.03%	42.73%	24.22%	29.90%	0.26%	0.87%
29	3.22%	60.62%	30.59%	3.25%	0.14%	2.19%
30	4.37%	65.17%	23.81%	3.74%	0.03%	2.89%
31	3.09%	64.91%	22.49%	6.71%	0.44%	2.35%
32	2.89%	65.78%	12.45%	6.37%	0.38%	12.13%
33	1.69%	54.01%	29.36%	9.11%	0.24%	5.59%
34	33.00%	38.37%	20.54%	5.57%	0.28%	2.25%
35	18.08%	33.94%	17.73%	22.94%	1.71%	5.61%
36	0.57%	76.04%	17.82%	3.33%	0.01%	2.24%
37	11.08%	51.08%	30.38%	6.86%	0.03%	0.57%
38	28.58%	32.09%	17.35%	20.96%	0.78%	0.24%
39	1.07%	64.84%	24.39%	8.08%	0.03%	1.59%
40	16.04%	49.73%	26.27%	3.05%	0.18%	4.73%
41	0.00%	75.47%	12.60%	0.00%	0.00%	11.94%
43	62.93%	0.47%	0.00%	35.72%	0.76%	0.12%

Source: FAF 2007 data

Note: Rail-truck mode proportion is zero.

Appendix Table 10: Foreign Export Mode proportion

SCTG	Air(including truck-air)	Truck-Water	multiple-Water	Truck-Truck	Truck-Multiple	Others
1	74.36%	0.82%	0.45%	23.77%	0.13%	0.48%
2	0.03%	8.43%	42.11%	0.94%	0.00%	48.48
3	3.29%	60.38%	26.95%	6.77%	0.09%	2.52%
4	0.35%	50.80%	43.11%	2.04%	0.00%	3.70%
5	0.32%	70.43%	10.86%	11.74%	0.01%	6.64%
6	0.97%	49.57%	19.69%	23.58%	0.00%	6.20%
7	4.64%	49.43%	11.58%	29.23%	0.01%	5.11%
8	2.87%	62.26%	20.35%	10.39%	0.00%	4.13%
9	0.05%	76.79%	15.88%	0.03%	0.00%	7.25%
10	0.00%	78.08%	13.05%	0.00%	0.00%	8.87%
11	0.00%	16.73%	22.58%	0.00%	0.00%	60.69
12	0.00%	60.05%	33.89%	0.00%	0.00%	6.06%
13	0.52%	74.19%	14.72%	5.99%	0.00%	4.59%
14	0.39%	14.64%	81.21%	0.10%	0.00%	3.67%
15	0.00%	68.78%	17.16%	0.00%	0.00%	14.06
16	0.00%	62.97%	16.60%	0.00%	0.00%	20.42
17	0.00%	47.31%	0.04%	0.00%	0.00%	52.65
18	0.00%	21.48%	23.96%	0.00%	0.00%	54.56
19	0.11%	56.54%	3.66%	8.62%	0.02%	31.04
20	5.06%	49.12%	18.11%	1.48%	0.00%	26.23
21	75.06%	9.16%	14.06%	1.10%	0.00%	0.62%
22	0.00%	23.56%	36.61%	32.97%	0.00%	6.86%
23	34.43%	28.73%	22.13%	12.04%	0.00%	2.68%
24	5.38%	25.01%	34.61%	29.12%	0.00%	5.88%
25	0.00%	48.54%	40.19%	0.00%	0.00%	11.27
26	1.17%	16.86%	11.77%	63.41%	0.02%	6.78%
27	0.00%	45.32%	40.21%	11.23%	0.00%	3.24%
28	4.15%	6.44%	4.02%	82.07%	0.05%	3.26%
29	32.50%	28.02%	8.75%	29.75%	0.00%	0.97%
30	16.85%	20.54%	19.73%	41.71%	0.03%	1.14%
31	13.46%	37.06%	21.56%	25.77%	0.01%	2.14%
32	11.08%	25.69%	11.18%	48.27%	0.02%	3.75%
33	16.52%	21.78%	7.78%	52.16%	0.02%	1.73%
34	49.10%	23.11%	10.02%	16.29%	0.00%	1.48%
35	70.82%	5.20%	2.96%	20.23%	0.01%	0.79%
36	5.10%	38.05%	18.30%	29.39%	0.00%	9.16%
37	77.11%	9.18%	3.25%	0.83%	0.00%	9.63%
38	75.21%	9.75%	5.83%	8.70%	0.00%	0.50%
39	12.09%	32.97%	19.36%	33.24%	0.01%	2.33%
40	53.01%	27.20%	8.48%	10.26%	0.00%	1.05%
41	0.00%	45.57%	46.06%	0.00%	0.00%	8.37%
43	3.07%	0.00%	0.00%	21.34%	0.00%	75.59

Source: FAF 2007 data

Note: Truck-rail mode proportion is zero.

Appendix Table 11: Domestic modes definition

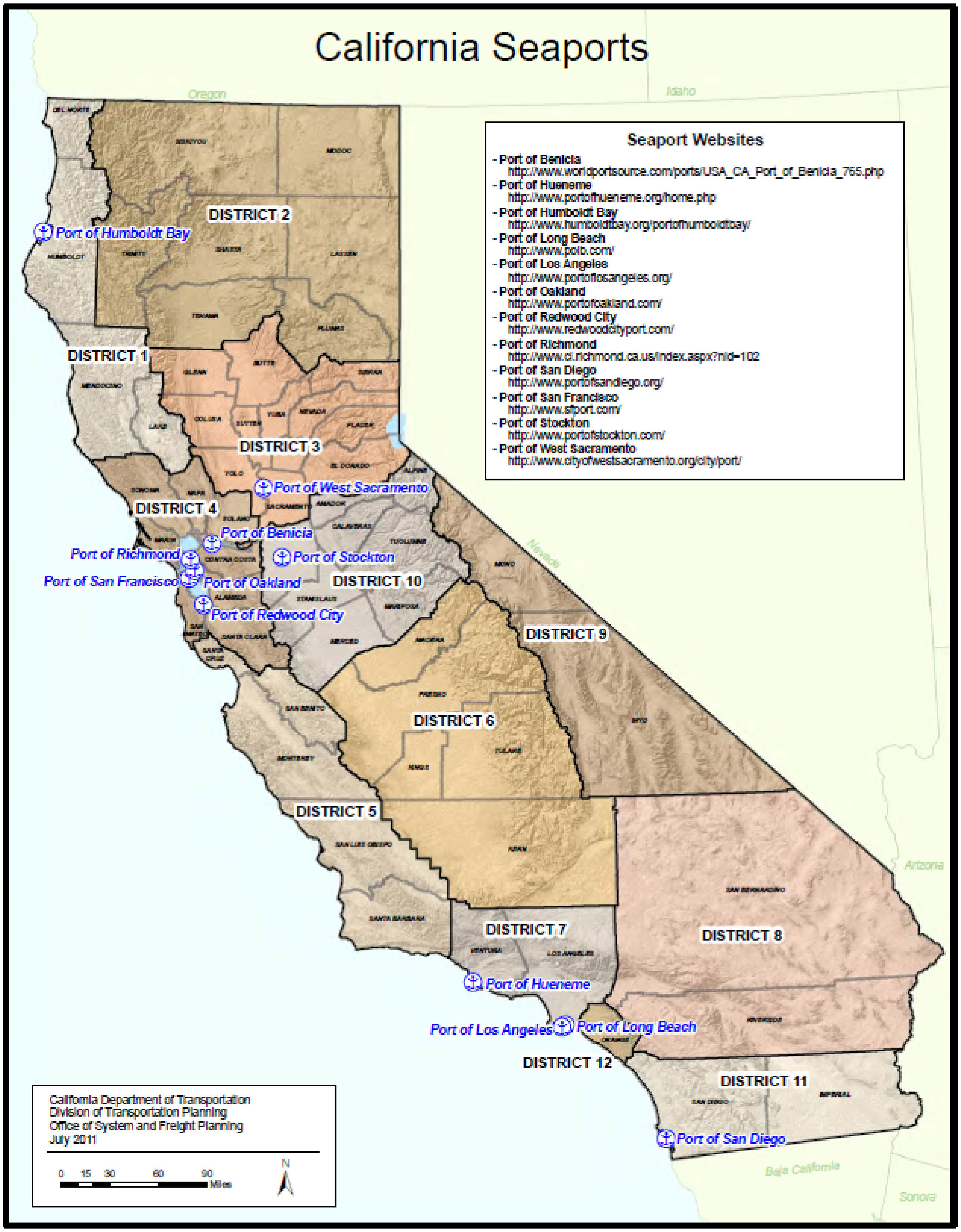
Mode ID	Mode Description	Remarks
1	Truck	Includes private and for-hire truck. Private trucks are owned or operated by shippers, and exclude personal use vehicles hauling over-the-counter purchases from retail establishments.
2	Rail	Any common carrier or private railroad.
3	Water	Includes shallow draft, deep draft and Great Lakes shipments.
4	Air (include truck-air)	Includes shipments typically weighing more than 100 pounds that move by air or a combination of truck and air in commercial or private aircraft. Includes air freight and air express. Shipments typically weighing 100 pounds or less are classified with Multiple Modes and Mail.
5	Multiple modes & mail	Includes shipments by multiple modes, parcel delivery services, U.S. Postal Service, and couriers. This category is not limited to containerized or trailer-on-flatcar shipments.
6	Pipeline	Includes shipments by pipeline and from offshore wells to land.
7	Other and unknown	Any mode not included within the other mode definitions and unknown modes of transport.
8	No domestic mode	Applies to some intra zonal movements of imports

Source: FAF database 2007

Appendix Table 12: Foreign modes definition

Mode ID	Mode Description	Remarks
1	Truck	Includes U.S. trade with Canada or Mexico that crosses the border on a private or for-hire truck.
2	Rail	Includes U.S. trade with Canada or Mexico that crosses the border on any common carrier or private railroad.
3	Water	Includes U.S. imports and exports that enter or exit the United States through a seaport.
4	Air	Includes U.S. imports and exports that enter or exit the United States through an airport.
5	Multiple modes & mail	Includes U.S. imports and exports that enter or exit the United States by multiple modes of transport, parcel delivery services, U.S. Postal Service, couriers, and U.S. imports and exports transhipped thru Canada or Mexico by a land mode (e.g. truck, rail, etc.) from/to a third country. This category is not limited to containerized or trailer-on-flatcar shipments.
6	Pipeline	Includes U.S. imports and exports that cross the U.S.-Canada or U.S.-Mexico border by pipeline.
7	Other and unknown	Any mode not included within the other mode definitions and unknown modes of transport. Includes flyaway aircraft, vessels and vehicles moving under their own power from the manufacturer to a customer and not carrying any freight, and imports into Foreign Trade Zones (FTZs).

Source: FAF database 2007



Seaport Websites

- Port of Benicia
  http://www.worldportsource.com/ports/USA_CA_Port_of_Benicia_765.php
- Port of Hueneme
  http://www.portofhueneme.org/home.php
- Port of Humboldt Bay
  http://www.humboldtbay.org/portofhumboldtbay/
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- Port of Los Angeles
  http://www.portoflosangeles.org/
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  http://www.redwoodcityport.com/
- Port of Richmond
  http://www.ci.richmond.ca.us/index.aspx?nid=102
- Port of San Diego
  http://www.portofsandiego.org/
- Port of San Francisco
  http://www.sfport.com/
- Port of Stockton
  http://www.portofstockton.com/
- Port of West Sacramento
  http://www.cityofwestsacramento.org/city/port/

California Department of Transportation
Division of Transportation Planning
Office of System and Freight Planning
July 2011

Appendix Figure 2: Sea ports in California

Source: California Department of Transportation http://www.dot.ca.gov/hq/tpp/offices/ogm/seaports.html)

Appendix Table 13: Reference Case Greenhouse Gas Emissions

GHG Emissions (Mt)	2006	2010	2015	2020	Avg. Annual Growth Rate 2006-2020
Residential	27.3	27.0	27.9	29.7	0.6%
Commercial	14.0	12.4	12.1	12.1	-1.0%
Industrial	80.0	86.2	92.8	102.8	1.8%
Energy Intensive Industry	52.5	47.8	48.6	49.2	-0.5%
Other Industry	27.5	38.4	44.2	53.6	4.9%
Mining	13.2	13.0	13.0	12.2	-0.6%
Agriculture	27.4	29.1	29.8	31.0	0.9%
Transportation	213.3	211.5	222.7	227.8	0.5%
Passenger	167.6	162.0	168.5	168.8	0.1%
Freight	45.7	49.5	54.2	58.9	1.8%
Power Sector	102.0	89.1	93.1	100.0	-0.1%
Domestic Power Sector	43.2	40.0	37.7	39.1	-0.7%
Electricity Imports	58.8	49.1	55.3	60.8	0.2%
Waste and Other	9.8	10.9	11.5	12.4	1.7%
Total	**486.9**	**479.3**	**502.8**	**527.9**	**0.6%**

Source: California Air Protection Agency | Air Resources Board
Updated Economic Analysis of California's Climate Change Scoping Plan | March 24, 2010

APPENDIX B: EMFAC 2007 and MOVES 2010a

EMFAC2007

The California Air Resources Board (ARB) has developed EMission FACtors (EMFAC) models. The latest model is EMFAC2007. It includes all motor vehicle data from motorcycles to heavy duty trucks. Emission rates are estimated for vehicles operated on highways, freeways, and local roads in California. Emission rates are calculated via the following equation:

$$\mathrm{E}_{\mathrm{ij}}^{\mathrm{c}} = \mathrm{EF}_{\mathrm{ij}}^{\mathrm{c}} \times \mathrm{CF}_{\mathrm{ij}} \times \mathrm{TA}_{\mathrm{ij}}^{\mathrm{c}}$$

Where

$\mathrm{E}_{\mathrm{ij}}^{\mathrm{c}}$ are emissions in tons per day by region i, calendar year j and vehicle class c

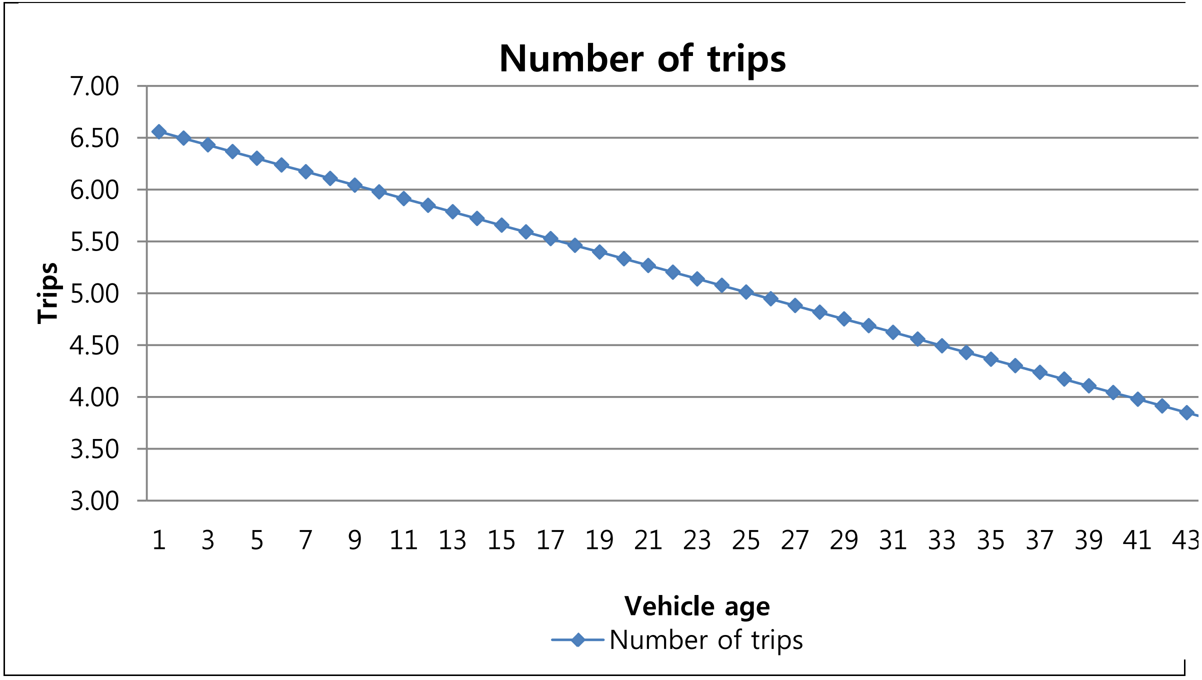
$\mathrm{EF}_{\mathrm{ij}}^{\mathrm{c}}$ are emissions factors (in grams per mile, grams per trip, and grams per vehicle)

$\mathrm{CF}_{\mathrm{ij}}$ are correction factors

$\mathrm{TA}_{\mathrm{ij}}^{\mathrm{c}}$ are vehicle activities

Correction factors reflect area-specific information affecting emission rates such as ambient temperature, relative humidity, and speed.

Vehicle activity refers to vehicle population, vehicle miles traveled (VMT) on a weekday, and vehicle trips for each vehicle class, fuel type and geographic area. Geographic areas can be one of four types: statewide, 15 air basins, 35 air pollution control districts, or 58 counties. EMFAC contains vehicle population data by vehicle classes, fuel types, regions, and vehicle age from 1 to 45 years. Vehicle populations are estimated by utilizing DMV vehicle registration data from base years 2000 to 2005. Data for 1970 to 1999 and 2001 to 2040 are estimated by back-casting and forecasting of the base year data. VMT is calculated by multiplying vehicle population to the vehicle accrual or total miles a vehicle traveled a year. VMT varies by vehicle age, class, and time of the day. Vehicle trips per day are the number of starts made per weekday. For vehicle classes 1 to 4, trips are estimated based on travel survey data and assumed to linearly decrease from 6.56 when vehicle age is 1 to 3.72 when vehicle age is 45 years. Figure 1 show the linearly decreasing graph. Trips for other classes are obtained either from engineering judgment or instrumented data. The number of trips per day is used to estimate starting exhaust.



Appendix Figure 3: Number of trips per weekday for vehicle class 1 to 4

Source: adapted from CARB, 2007

Air pollutants

The model estimates emission inventories for four pollutants, Hydrocarbons (HC), Carbon monoxide (CO), Carbon dioxide (CO2), Nitrogen oxides (NOx), and Particulate matter (PM10, PM2.5). Fuel consumption is calculated by applying a carbon balance equation showing the relationship between fuel consumption and emission inventories such as CO, CO2 and HC. Emission inventories of Oxides of sulfer (SOx) are calculated by multiplying fuel consumption with the percentage of SOx in a gallon of fuel.

Appendix Table 14: Air pollutants estimated in EMFAC 2007

Pollutant		Full name	Description	Unit	
Direct estimation	HC	Hydrocarbons	HC is equivalent to TOG(total organic gases), ROG (reactive organic gases), THC (total hydrocarbon), or CH4 (methane)	grams	Emission rates are estimated directly from vehicle activities
	CO	Carbon monoxide	vehicle activities	grams	
	CO2	Carbon dioxide		grams	
	NOx	Nitrogen oxides		grams	
	PM	Particulate matter	Particulate matter 10 microns or less in diameter (PM10),	grams	

			Particulate matter 2.5 microns or less in diameter (PM2.5)		
Indirect estimation	Sox	Oxides of sulfur		grams	Emission rates are estimated indirectly by applying fuel consumptions
	Pb	Lead	Estimated until year 1991 and Zero from year 1992.	grams	

Source: Summarized from CARB, 2007

Emission processes

Nine emission processes are considered in the EMFAC model as shown in Table 2.

Appendix Table 15: Emission processes in EMFAC 2007

	Process	Emitted areas	Activities of emission	Applied vehicle	Pollutants
Exhaust	Running exhaust	Tailpipe	While traveling on the road	All vehicles	CO, NOx, CO2, SOx
	Idle exhaust	tailpipe	While operating for loading and unloading goods	Heavy-duty trucks	CO, NOx, CO2, SOx
	Starting exhaust	tailpipe	While starting a vehicle	Only for gasoline fueled vehicles	CO, NOx, CO2, SOx
Evaporative	Diurnal	Fuel system, fuel hoses, connectors, carbon canister	From 35 minutes of sitting after finishing operation and ambient temperature is increasing.	All vehicles	HC
	Resting loss	Fuel system, fuel hoses, connectors, carbon canister	From 35 minutes of sitting after finishing operation and ambient temperature is not increasing.	All vehicles	HC
	Hot soak	Fuel injector, Fuel hoses	Immediately after a trip end until 35 minutes	All vehicles	HC
	Running losses	Fuel system, carbon canister	While operating	All vehicles	HC
Wear	Tire wear	Tires	While moving	All vehicles	PM
	Break wear	Brake	While using brakes	All vehicles	PM

Source: Summarized from CARB, 2007

Vehicle class and technology group

Emission rates are estimated separately for 13 vehicle classes in the model. Vehicle classes are car types such as passenger cars, trucks, motorcycles, buses, and motor homes. Truck class is broken down into 7 sub classes by vehicle weights. Vehicle classes are broken down further into technology groups. The basic assumption of a technology group is that vehicles of each technology group have the same emission rates due to installed emission control devices in vehicles. A technology group can include more than one vehicle class. There are two types of technology groups: exhaust and evaporative technology groups. Exhaust technology groups are related to emissions such as CO, NOx, CO2 and SOx that come out of the tailpipe while operating. Evaporative technology groups are related to HC emissions that are evaporated from fuel systems.

Three modeling modes in EMFAC 2007

EMFAC 2007 supports three modeling modes such as Burden, Emfac and Calimfac.

Appendix Table 16: Three modeling modes in EMFAC 2007

	Burden	Emfac	Calimfac
Result	Total emissions in tons per weekday. Vehicle population, VMT(mi/day), and trips (per day)	Emission factors in grams per vehicle activity (grams per mile, grams per hour, grams per start and depends on emissions process)	Basic emission rates (g/mi)
Common classification	For each pollutant by 13 vehicle classes, geographic area, season, calendar year, emission processes, vehicle model year	For each pollutant by 13 vehicle class, geographic area, season, calendar year, emission processes, vehicle model year	For each pollutant by 13 vehicle classes, geographic area, season, calendar year, emission processes, vehicle model year
Specific		By temperature, relative humidities, speed,	By technology group and vehicle age, with/without I/M program

Source: Summarized from CARB, 2007

MOVES 2010a

The U.S. Environmental Protection Agency (EPA) has developed a comprehensive air pollution emissions estimation model, Motor Vehicle Emission Simulator (MOVES). The latest version is MOVES2010a. The basic concept of emission estimation processes is similar to the one used in EMFAC2007. The emission calculation process is similar to EMFAC. However, primary activity data that is used to estimate emission inventory is significantly different. Initial data to estimate running exhaust emissions is VMT which is the same as for EMFAC. The VMT, however, are converted into Source Hours and Source Hours Operating (SHO).

MOVES consists of five major frameworks: activity generator, source bin distribution generator, operating mode distribution generator, energy consumption calculator, and emission calculator. VMT is converted to source hours and source hours operating (SHO). Each activity basis for emission processes is explained in Table 4. Source bin refers to vehicle classes that are similar to technology group in EMFAC. Table 5 explains source bin. An operating mode is a combination of Vehicle Specific Power (VSP) and speed. Table 6 shows operating mode bins.

Whole processes of emission rate calculation can be simplified (Bai, 2009). Base emission rates are first adjusted by area specific data such as Inspection and Maintenance (I/M) program, temperature, and relative humidity. Then the adjusted emission rates are weighted by source bin and operating mode bin fractions. Finally total emission inventories are estimated by multiplying total activity with the weighted emission rates.

Appendix Table 17: Total Activity Basis by Process

Emission Process	**Total Activity Basis**	**Description**
Running Tire wear Brake wear	Source Hours Operating (SHO)	Total hours, of all sources within a source type, spent operating on the roadway network for the given time and location of the run spec. The same as number of sources * per-source hours operating
Evaporative Fuel Permeation, Vapor Venting and Leaking	Source Hours	Total hours, of all sources within a source type for the given time and location of the run spec. This is equivalent to the population of the source type times the number of hours in the time period.
Start	Number of Starts	Total starts, of all sources within a source type, for the given time and location of the run spec. The same as number of sources * per-source starts
Extended Idle	Extended Idle Hours	Total hours, of all sources within a source type, spent in extended idle operation for the given time and location of the run spec.

Source: EPA, 2009: page 39

Appendix Table 18: MOVES Source Bin Definitions (other than Model Year Group)

Fuel Type (All Pollutants)	Engine Technology (All Pollutants)	Loaded Weight (Energy)	Engine Size (Energy)	Regulatory Class (All pollutants except energy and evap permeation)
Gas Diesel CNG LPG Ethanol (E85) Methanol (E85) Gas H2 Liquid H2 Electric	Conventional IC (CIC) Advanced IC (AIC) Hybrid - CIC Moderate Hybrid - CIC Full Hybrid - AIC Moderate Hybrid - AIC Full Fuel Cell Hybrid - Fuel Cell Electric	Null < 500 (for motorcycles) 500-700 (for motorcycles) > 700 (for motorcycles) <= 2000 lbs 2001-2500 2501-3000 3001-3500 3501-4000 4001-4500 4501-5000 5001-6000 6001-7000 7001-8000 8001-9000 9001-10,000 10,001-14,000 14,001-16,000 16,001-19,500 19,501-26,000 26,001-33,000 33,001-40,000 40,001-50,000 50,001-60,000 60,001-80,000 80,001-100,000 100,001-130,000 >=130,001	Null < 2.0 liters 2.1-2.5 liters 2.6-3.0 liters 3.1-3.5 liters 3.6-4.0 liters 4.1-5.0 liters > 5.0 liters	Null Motorcycle LDV LDT HD gasoline GVWR <= 14K lbs HD gasoline GVWR > 14K llbs. LHDD MHDD HHDD Urban Bus

Source: EPA, 2009: page 34

Appendix Table 19: MOVES Source Bin Definitions (Model Year Group)

Model Year Group					
Energy	CH4, N2O	HC - Evap	HC, CO, NOx, PM start, running	HC, CO, NOx, PM extended idle	Sulfate PM (ratios to energy)
1980 and earlier 1981-85 1986-90 1991-2000 2001-2010 2011-2020 2021 and later	1972 and earlier 1973 1974 1975 . . . 1999 2000 2001-2010 2011-2020 2021 and later	1970 and earlier 1971-1977 1978-1995 1996-2003 2004 2005 . . 2019 2020 2021 and later	1980 and earlier 1981-1982 1983-1984 1985 1986-1987 1988-1989 1990 1991-1993 1994 1995 . . 2019 2020 2021 and later	1980 and earlier 1981-85 1986-90 1991-2000 2001-2006 2007-2010 2011-2020 2021 and later	1980 and earlier 1981 and later

Source: EPA, 2009: page 34

Appendix Table 20: Operating Mode Bin Definitions

Braking Bin 0			
Idle Bin 1			
VSP\Instantaneous Speed	**0-25 mph**	**25-50**	**<50**
<0 kW/ton	Bin 11	Bin 21	
0 to 3	Bin 12	Bin 22	
3 to 6	Bin 13	Bin 23	
6 to 9	Bin 14	Bin 24	
9 to 12	Bin 15	Bin 25	
12 and greater	Bin 16	Bin 26	Bin 36
6 to 12			Bin 35
<6			Bin 33
12 to 18		Bin 27	Bin 37
18 to 24		Bin 28	Bin 38
24 to 30		Bin 29	Bin 39
30 and greater		Bin 30	Bin 40

Source: EPA, 2009: page 40

Comparison of EMFAC and MOVES model

Table 7 shows a comparison of EMFAC2007 and MOVES2010a

Appendix Table 21: Comparison of EMFAC2007 and MOVES2010a

	EMFAC2007	MOVES2010a
Geographic area	California state, 15 air basins, 35 air pollution control districts, or 58 counties	U.S. as a nation, 53 States (District of Columbia, Puerto Rico, U.S. Virgin Islands are considered to be states), 3222 counties, 5 Links in each county
Pollutants	Hydrocarbons (TOG, ROG, THC, or CH_4) Carbon monoxide (CO) Carbon dioxide (CO_2) Oxides of Nitrogen (NOx) Particulate matter (PM10, PM2.5) Oxides of sulfur (SOx) Lead (Pb) Fuel consumption	Hydrocarbons (TOG, VOC, THC, or CH_4) Carbon monoxide (CO) Carbon Dioxide (CO_2: depends on total energy con.) CO2 equivalent (CO_2e) Oxides of Nitrogen (NOx, NO, NO_2) Nitrous Oxide (N_2O) Particulate matter (PM10, PM2.5) Sulfur Dioxide (SO_2) Total Energy Consumption (Petroleum and Fossil Fuel) Ammonia (NH_3) Naphthalene ($C_{10}H_8$ -depends on PM10) Below emissions depends on VOC Benzene (C_6H_6) Ethanol (C_2H_6O) methyl tertiary butyl ether (MBTE)($C_5H_{12}O$) 1,3-Butadiene(C_4H_6) Formaldehyde(CH_2O) Acetaldehyde(C_2H_4O) Acrolein(C_3H_4O)
Vehicle class	PassengerCars Light-DutyTrucks(0-3750) Light-DutyTrucks(3751-5750) Medium-DutyTrucks(5751-8500) Light-Heavy-Duty(8501-10000) Light-Heavy-Duty(10001-14000) Medium-Heavy-Duty(14001-33000) Heavy-Heavy-Duty(33001-60000) Other Buses Urban Buses Motorcycles School Buses Motor Homes	Passenger Cars Passenger Trucks Light Commercial Trucks Refuse Trucks Single Unit Short-haul Trucks Single Unit Long-haul Trucks Combination Short-haul Trucks Combination Long-haul Trucks Intercity Buses Transit Buses Motorcycles School Buses Motor Homes
Fuel type	Gasoline Diesel	Gasoline Diesel

	Electricity	Electricity Compressed Natural Gas (CNG) Liquid Propane Gas (LPG) Ethanol (E85) Methanol (M85) Gaseous Hydrogen Liquid Hydrogen
Emission process	Running Exhaust Starting Exhaust Idle Exhaust Diurnal Hot soak Resting loss Running losses Tire Wear Brake Wear	Running Exhaust Starting Exhaust Extended Idle Evaporative Fuel Permeation Evaporative Fuel Vapor Venting Evaporative Fuel Leaking Refueling Spillage Loss Refueling Displacement Vapor Loss Tire Wear Brake Wear
Time period	Calendar years 1970-2040. Output by hour of weekdays, month, season (summer, winter), and year	Calendar years 1990 and 1999 through 2050. Output by hour of the day, weekday, weekends, month, and year
Vehicle model year	1965 – 2040	1960-2050
Activity data for running exhaust	Vehicle Miles Traveled (VMT)	Source Hours Operating (SHO): operating time by combination of Vehicle Specific Power (VSP) and speed
Road Type	Not available	Rural Restricted Access (i.e. freeways and interstates) Rural Unrestricted Access Urban Restricted Access (i.e. freeways and interstates) Urban Unrestricted Access Off of the highway network (for start, idle, evap.)

Source: Summarized from CARB, 2007 and EPA 2009, 2010a