A GRID-BASED MOBILE SOURCES EMISSIONS INVENTORY MODEL

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CHAPTER 1. INTRODUCTION

1.1 Background

The Clean Air Act Amendments (CAAA) of 1990 established a process that requires nonattainment areas to reduce emissions in order to attain the National Ambient Air Quality Standards (NAAQS). The emissions are categorized by their sources – mobile, stationary, and area sources (Chatterjee *et al.,* 1997). The state implementation plan (SIP), which is developed to ensure that states meet the NAAQS, establishes emissions limits (also called emission budgets) for each source within the nonattainment areas. The link between mobile source budgets and the SIPs is known as the “transportation conformity” (or “conformity”) rule. This statutory mandate was implemented in November 1993 by the United States Environmental Protection Agency (USEPA), with the concurrence of the United States Dept. of Transportation (USDOT) (Howitt, 1999). Conformity is designed to ensure that transportation investments are consistent with state commitment for meeting the NAAQS.

According to conformity regulations, a procedure called the “budget test” is required to determine whether or not transportation plans “conform”. Metropolitan Planning Organizations (MPOs) must show that expected emissions from mobile sources are within the mobile source emission budgets contained in the applicable SIP. Transportation programs must also provide for timely implementation of any transportation control measures that are included in approved SIPs. Conformity determinations are accomplished by combining transportation forecasting model (usually standard four-step travel demand models) output with a mobile emissions inventory model and a USEPA-approved emissions rates to estimate a 20-year forecast of mobile source emissions. The travel demand models must account for changing demographics, land uses, economic development, *etc*. Estimated emissions inventories from several milestone years are then compared with the maximum emissions permissible under the applicable SIPs (Howitt, 1999). This procedure is summarized in Figure 1. As we can see, the emissions inventory model is the computational heart of the conformity process.

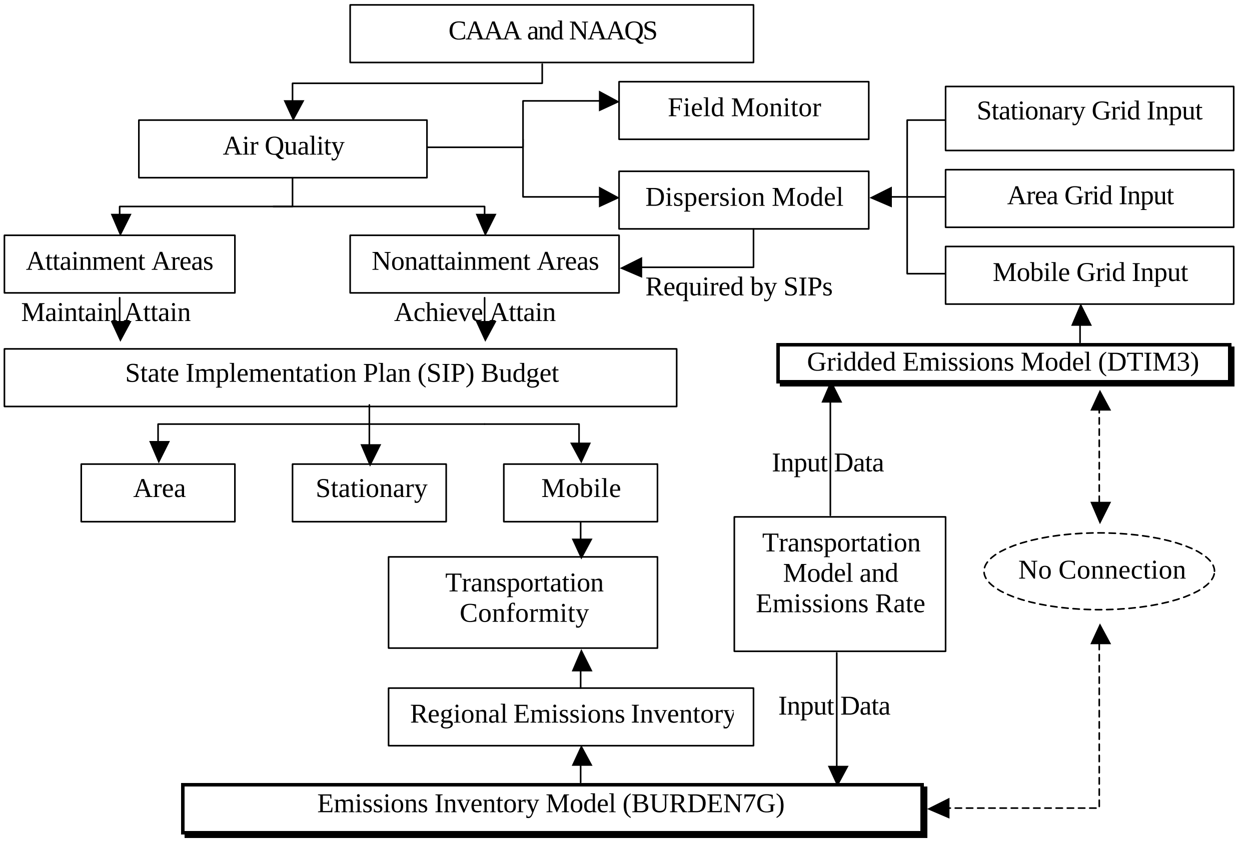

Figure 1. Relation of CAAA, NAAQS, SIP, Conformity, Transportation, Emissions Rates, and Emissions Inventory Models[1]

Also shown in Figure 1, SIPs require nonattainment areas (classified as Serious or Higher) to submit a plan demonstrating how additional emissions reductions, as estimated by the pollutant dispersion models (e.g., Urban Airshed Model), will be achieved (Chatterjee *et al.*, 1997). Gridded mobile source emissions must be provided to run the dispersion models.

As we can see from Figure 1, two different types of vehicle emissions inventories (regional emissions inventory and gridded emissions) must be developed. In California, these emissions are calculated separately using two different models with no interaction between them. The two emissions inventory models are the BURDEN[1] series model, the vehicle emissions inventory model developed by the California Air Resources Board (CARB), and the DTIM series model developed by the California Dept. of Transportation (Caltrans) to prepare gridded emissions. Although DTIM was originally developed for preparing gridded input for dispersion models, it

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[1] BURDEN7G and DTIM3 are the versions of BURDEN and DTIM models currently widely used in California. BURDEN is a component in the MVEI system (consists of WEIGHT, EMFAC, REPORT, and BURDEN). The latest version of MVEI system is EMFAC2000 (ver. 2.02). Source: http://www.arb.ca.gov/msei/msei.htm.

has often been used to estimate regional vehicle emissions inventories (Niemeier and Ito, 2000). Theoretically speaking, even though the two models use different methodologies, they should generate comparable emissions estimates when aggregated to the same spatial level (e.g., county total emissions). However, large gaps between their inventory estimates are always found.

Both models suffer from limitations when implemented. For instance, BURDEN can only develop regional total emissions and is not capable of estimating gridded emissions, and is not directly connected to the transportation forecasting models. That is, the transportation modeling results must be aggregated to daily totals for use in BURDEN which then disaggregates the daily VMT to period VMT.

Alternatively, DTIM has a major methodological weakness. An emissions inventory model, such as BURDEN, multiplies transportation speed-VMT data by the appropriate emissions rates to develop the emissions inventory estimates. Generally, there are three levels of interface between transportation data and emissions rates, ranging from individual vehicle level to trip level (Figure 2). The transportation data and emissions rates must sit at the same level to be methodologically sound. However, as we can see below, DTIM inappropriately applies link-based activity data from transportation models to an upper-level trip-based emissions rate. It is not clear whether the trip-based emissions rates are as valid for the homogeneous link speeds (where speed variance is less significant) as they are for average trip speeds.

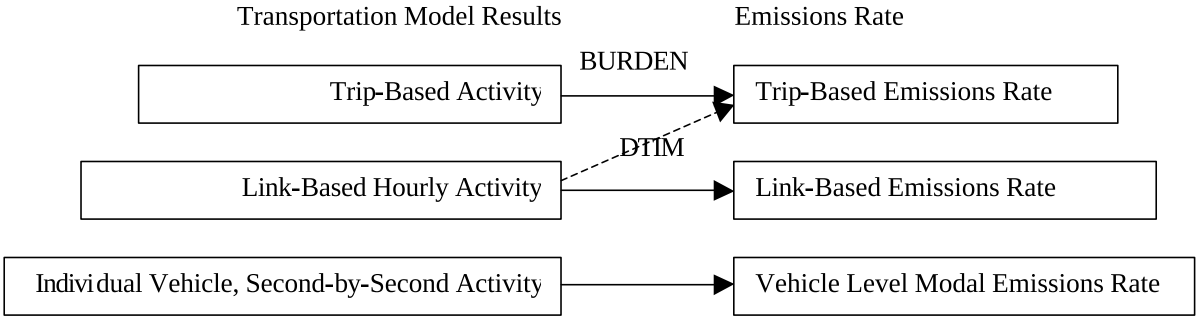

Figure 2. Level of Transportation/Emissions Rates Interface

CARB recently released the latest MVEI system, EMFAC2000 (ver. 2.02), where the previously separate functional components for developing basic emission rates (BER), applying inspection/maintenance effects and correction factors, and calculating the emissions inventory are integrated (CARB, 2001*a*, *b*). Compared to MVEI7G, EMFAC2000 represents substantial improvements to trip speed based emissions rates and emissions inventory development.

However, because its emissions rates are still trip-based rates, and its activity interface and fundamental formulas for emissions estimations still utilize link based transportation model results, EMFAC2000 inherits all the weakness described above.

1.2 Study Purpose

In general, the limitations of the current California vehicle emissions inventory models can be summarized as:

- There is no direct connection between the regional emissions inventory model and the gridded emissions model. Separate model runs must be processed to develop regional emissions inventories and gridded emissions.
- The emission estimates from the regional emissions inventory model and the gridded emissions model are not in agreement.
- The regional emissions inventory model is not directly connected to the transportation forecasting models.
- The gridded emissions model has an inappropriate interface between the transportation data and the emissions rates.

The purpose of this study is to develop a new transportation and emission interface model. This requires advancing the knowledge with respect to gridded emissions calculations, as well as improving current spatial computations of emissions. Oriented at the grid cell level, the new model will establish a direct connection between regional emissions inventories for conformity and gridded emissions for airshed dispersion modeling.

The new model will be able to use transportation data from the standard four-step travel demand models, and emissions rates from EMFAC2000 or a set of newly developed link-based facility-specific CAMP running exhaust emissions rates. EMFAC2000 represents the latest understanding of mobile emissions development. Its algorithm and methodologies on basic emission rates development, driving cycle adjustment, speed adjustment factors, vehicle fleet age distribution, and traffic activity data significantly improve the emissions inventory estimates (Gao *et al.*, 2001). Alternatively, the link-based CAMP emissions rates disaggregate travel activities by facility type, so that emissions rates will more closely represent link-level emissions than previously available. When developing emissions inventories, both transportation data and emissions rates will sit at the link level. This will ensure that transportation data and emissions rates in the new model sit at the same level of interface (see Figure 2), and the model will be methodologically sound.

The implementation of the new model will be flexible with the ability to model areas ranging from county level to individual project level. The spatial and temporal emissions evaluation can be conducted at any level of the model's implementation.

1.3 Organization

The proposal is organized into five chapters. Chapter 2 provides a broad overview of related research in transportation and emissions modeling. A summary of the available transportation, emissions rates, and emissions inventory models is presented, and their strengths and weaknesses are discussed. Model development trends are discussed at the end of the chapter.

Chapter 3 provides an in-depth evaluation of the two emissions inventory models widely used in California (BURDEN7G and DTIM3). The strengths and weaknesses of each model are discussed. The chapter concludes with a summary of the challenges and motivations behind the proposed new interface model.

Chapter 4 presents the design of the new transportation and emission interface model. The model structure, required transportation data, emissions rates, and the interface of transportation data and emissions rates are discussed. Finally, Chapter 5 discusses the strengths and weaknesses of the new model.

CHAPTER 2. LITERATURE REVIEW

It is necessary to understand the interrelationship between the transportation, emissions rates, and emissions inventory models before discussing the development of the new interface model. To start, transportation models are used to provide emission-specific transportation activity data, such as vehicle miles traveled (VMT), vehicle hours traveled (VHT), speed, and volume. The emissions rates models provide emissions rates for various combinations of vehicle types and vehicle activities. The emissions inventory models use transportation activity data in conjunction with emissions rates and other travel activity data to calculate total vehicle emissions (Figure 3). The outputs from the emissions inventory models are then used in various mobile source emission analyses, such as conformity. Therefore, the resulting emissions estimates of an emissions inventory model fundamentally depend on three components:

- The transportation data from a transportation model,
- The emissions rates from an emissions rates model, and
- The interface between transportation data and emissions rates in the emissions inventory model.

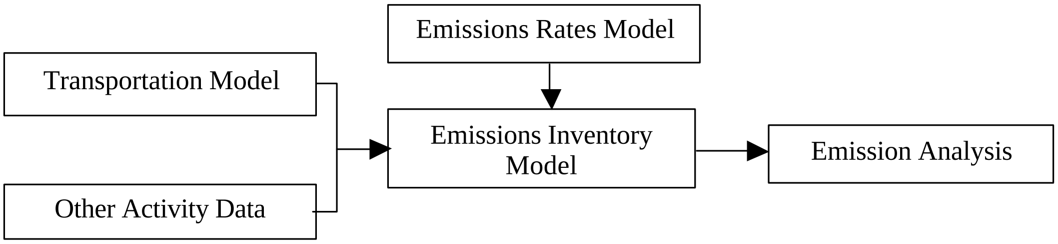

Figure 3. Simplified Vehicle Emission Prediction Procedure

This chapter reviews the current state of knowledge in these three areas: transportation models, emissions rates models, and emissions inventory models. The methodologies and outputs that affect the emissions estimates are discussed. The model development trends are summarized at the end of the chapter. In short, this chapter will:

- Introduce the emission-specific transportation data and emissions rates,
- Identify the strengths and weaknesses of the current transportation, emissions rates, and emissions inventory models, and
- Identify the optimal transportation model and emissions rates model to prepare input data for the proposed new interface model.

2.1 Transportation Models

In California, a common and highly useful information source for the preparation of emissions inventory is the transportation model. Transportation models can be generally classified into four types:

- Trip-based static travel demand models,
- Trip-based dynamic travel demand models,
- Activity-based travel models, and
- Traffic simulation models.

Trip-based static travel demand models produce link-based travel data by multi-hour time period, while the results of trip-based dynamic travel demand models are given by smaller time slice. Activity-based travel models can generate individual vehicle activities, mostly commonly represented through trip chaining. Traffic simulation models work with either trip-based or activity-based models to simulate second-by-second vehicle movements, usually limited to a single corridor.

Generally speaking, a modeling region is divided into Traffic Analysis Zones (TAZs). There are three basic types of movements tracked in the modeling region. They include (Ghareib, 1996):

- Interzonal movements, with origins and destinations in different TAZs but inside the modeling region,
- Intrazonal movements, with origins and destinations in the same TAZs and inside the modeling region, and
- External movements with portions of trips occurring in the modeling region, but either (both) their origins or (and) their destinations are outside the modeling domain.

The emission-related outputs from transportation models are link speeds, link volumes, link distances, and number of trips. As will be discussed in the following sections, each of the four types of transportation models produces slightly different output, which in turn affects emissions.

2.1.1 Trip-Based Static Travel Demand Models

Standard travel demand models are trip-based static models, which means that trips departing in a time period (e.g., peak period) must reach their destinations within the same period (Donaghy *et al.*, 1998). The primary purpose of this type of model in the 1960s and 1970s was to determine the need for major highway or transit investment (Outwater and Loudon, 1994). Rough approximations of forecast volumes were sufficient for these purposes. With the new transportation-air quality regulatory and legislative environment, the need for good estimates from travel demand models has been expanded to include link volumes and speeds, and number of trips, by multi-hour time periods for use in emissions inventory predictions.

The standard travel demand model consists of four sequential steps (Ortuzar and Willumsen, 1995): trip generation, trip distribution, mode choice, and trip assignment (Figure 4). The prototypical model of this type was implemented on a mainframe computer in the Urban Transportation Planning Packet (UTPS) modeling system. More recently, several workstation and PC implementations have been developed, including MINUTP, TRANPLAN, EMME2, SYSTEM II, TMODEL and QRS (Skabardonis, 1994). All the models follow the same four-step modeling framework. After the trip assignment step, some models include a feedback loop to mode choice or trip distribution to reconcile the output travel speeds implied by assigned volumes to the input speeds assumed at earlier stages of the process (Johnston and Ceerla, 1996). However, to date, this feedback mechanism has not been widely used by MPOs in their modeling structures (Hartgen *et al.*, 1995).

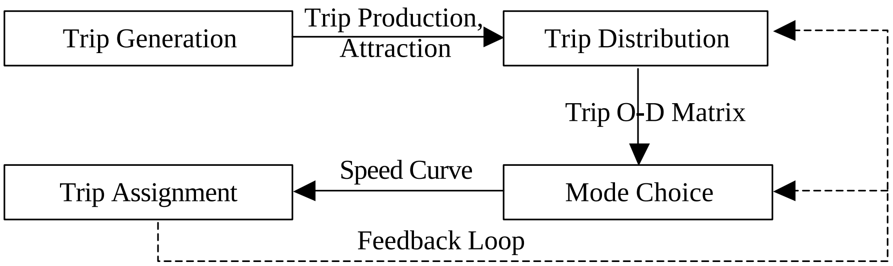

Figure 4. Steps of Static Travel Demand Model

In practice, the standard travel demand models are often integrated with land use models to predict transportation activities (Johnston *et al.*, 1998). Outputs, such as number of trips, link volumes, distances and average speeds, serve as inputs to vehicle emissions inventory models (DeCorla-Souza *et al.*, 1994). The link speeds are generally considered to be unreliable as estimates of true roadway network speeds (Hartgen *et al.*, 1995; Systems Application

International, 1998*a*). Also, there have been a significant number of implementation problems, such as an inability to predict intrazonal and off-network trips, the lack of feedback components, insufficient current socioeconomic data, and inadequate evaluation procedures (Harvey, 1991; Outwater, 1994). Model results are arguably of lower accuracy. For example, UTPS has an accuracy range of 5~30% error in overall VMT estimates and 5~20 mph error in average speeds (Miller, 1995).

As the understanding of emission behavior expands, more detailed vehicle activities, such as hourly link volumes, accurate link speeds, and activity durations, are desired. Many studies have been conducted to improve the standard travel demand models results specifically for emissions inventory modeling. Several post-processing techniques have been developed to improve the prediction of standard travel demand models estimated speeds (Dowling, 1992; Helali and Hutchinson, 1994; Systems Application International, 1994*a*; Skabardonis, 1997); to disaggregate daily (or time-period) link volumes into hourly volumes (Quint *et al.*, 1994; Knowles *et al.*, 1995*a*; Niemeier *et al.*, 1999); to adjust daily volumes into season-specific volumes (Quint *et al.*, 1994; Benson *et al.*, 1994); and to disaggregate trips into a single occupancy, carpool and vanpool (Everett, 1998).

Other research has been conducted to predict link volumes for shorter time periods by including pre-peak/offpeak and post-peak/offpeak period assignments in addition to the standard peak and offpeak period assignments (Eash, 1998); to determine off-network (local) VMT based on the traffic monitoring systems (Flood, 1998); to directly estimate VMTs by running modes (e.g., cold start, hot start, and hot stabilized mode) using a specialized equilibrium assignment model (Venigalla *et al.*,1999), and to divide the standard travel demand model output into emission-homogeneous speed-flow regions, which are associated with different sets of disaggregated emissions rates (Roberts *et al.*, 1999).

Using the above efforts, most standard travel demand model results can be converted into the kinds of detailed data required by the emissions inventory models. However, these post-processor methods are still based on the results of the standard travel demand models. If travel demand model results are arguably of lower confidence, so will be the results of post-processors. Furthermore, because most post-processors are based on the surveys or traffic monitoring where traffic conditions vary, they are also specific to a certain region and year. Different sets of data have to be prepared and frequently updated for application in different regions.

2.1.2 Trip-Based Dynamic Travel Demand Models

Trip-based dynamic travel demand models estimate the same types of travel data as the static models, but with smaller time slices under a different methodology. In a static travel demand model, all trips between any origin and destination are assumed to be completed within the specific modeling period. However, the static assumptions don't always hold in the real world. Dynamic models, typically used for Intelligent Transportation System (ITS) projects, help to overcome this limitation.

The temporal variation in travel demand is taken into account by disaggregating time periods into finite time-slices. During the assignment, each origin-destination pair progresses to the extent possible within each time slice. Consequently, a trip may take several time slices to reach its destination, or may not reach it within the time period being modeled (Murthy, 1998). Details of the modeling methodology are discussed in greater detail elsewhere (e.g., Cassetta *et al.,* 1994).

The effect of dynamic assignment models is to stretch the peak hour. The more congested the peak hour, the greater the stretch (Murthy, 1998). This phenomenon of peak spreading occurs in reality. In practice, dynamic models are often combined with traffic simulation models to provide detailed vehicle activity data for the use of emissions inventory models. The model outputs are discussed together with traffic simulation models in Section 2.1.4.

2.1.3 Activity-Based Transportation Models

The activity-based approach predicts travel demand based on the decision process underlying travel behavior: demand for activities produces demand for travel. Activity-based models are usually composed of four modules (RDC Inc., 1995): a baseline activity-travel pattern analyzer, a travel demand management response option generator, an activity-travel pattern modifier, and an evaluation module. Sitting at the end is a feedback loop from the evaluation module to the response option generator. The basic data for the model is a detailed travel activity survey.

Activity-based travel models can estimate individual/aggregate travel data, such as VMT, number of trips by mode and time of day, number of stops by purpose, individual trip chains, speed, activity duration by purpose, vehicle occupancy, cold and hot starts, and so on (RDC Inc., 1995; Lee and McNally, 1998). The model, thus, has the potential to predict very detailed emission-specific vehicle activities. Although activity-based models may have long-term promise, there are near-term implementation barriers. Several reasons why this type of model unlikely to be implemented on a widespread basis in the near future include (Suhrbier *et al*., 1997):

- The need to demonstrate methodological feasibility and practicality for US travel modeling,
- The lack of acceptance of such methods by MPOs and state DOTs as an alternative to standard four-step travel demand modeling process,
- Increased data requirements, and
- Lack of in-home activity information in most household surveys, such as potential responses to traffic control measures.

Thus, activity-based models have not to date been widely used in developing travel data for emissions estimates.

2.1.4 Traffic Simulation Models

Simulation models have been developed over the last twenty years for traffic flow on roadway systems. These models are often described as the solution to the problems facing the standard travel demand models (Bachman, 1998). Simulation models can be deterministic or stochastic and generally come in two forms: macroscopic or microscopic. Macroscopic models approximate traffic flow as a fluid and use a road segment as a base unit. A major limitation of macroscopic models, however, is that they estimate time spent in each driving mode (cruise, acceleration and deceleration) based on average flow rates and certain simplified assumptions (e.g., constant rates of acceleration/deceleration) instead of a detailed simulation of each vehicle's travel paths (Skabardonis *et al.*, 1994). Microscopic models, also called microsimulation models, track individual vehicles as well as their relationship to other vehicles. Microscopic simulations produce second-by-second vehicle movement as the vehicle travels in the network. Therefore, microsimulation can provide detailed traffic data for emission analysis.

Some microscopic models include a trip assignment algorithm (e.g., ATMS, TRANSIMS, and DYNASMART), while others require link volumes as input to the simulation models, which in turn predict the time spent by driving mode. If the trip assignment step uses a dynamic trip assignment algorithm, the simulation model is considered dynamic. Otherwise, it's a static simulation model.

By their nature, simulation models have the theoretical and computational capability to predict regional facility-level data at a resolution needed to predict emission-specific activity. However, most models are developed to answer specific problems in a local network, such as traffic congestion around a shopping mall, instead of describing complete system activity (Reynolds and Broderick, 2000).

For example, the INTRAS model (Wick and Liebermann, 1980) was used to simulate vehicle movement on freeways and ramps based on car-following, lane changing and queue discharge algorithms. FRESIM (Halati and Torres, 1990), a model which succeeded INTRAS, improved the representation of driver behavior, the logic for merging and lane changing, and the modeling of real-time ramp metering. ATMS (Junchaya *et al.*, 1992), a traffic simulation model, employed parallel processing to simulate vehicle movement based on real-time link travel time by small time slices. Finally, the INTEGRATION model (Van Aerde, 1992; Berkum, *el al.*, 1996) simulated individual vehicle movements including those with route guidance systems. The focus of these models is mainly on the solution of various traffic flow problems in small transportation networks.

A newer generation of microsimulation models, with a broadened scope and designed around regional systems, can be used to provide detailed regional travel data for emission estimates. These models include:

- MICE is a dynamic traffic assignment-simulation model (Adamo *et al.*, 1996). The model performs dynamic network loading using a point packet approach and allowing en-route modification of chosen paths. The model guarantees both the flow propagation consistency with the travel time on links and the first-in first-out (FIFO) rule. However, a commercial model is not available.

- TRAF-NETSIM simulates second-by-second speeds and accelerations of individual vehicles (Chatterjee *et al.*, 1997). The standard four-step travel demand models provide link volumes to the simulation model. The model can simulate the effects of alternative designs and traffic control strategies ranging from stop signs to traffic responsive control. The model can also handle transit movements, parking activity, and street blockages.

- TRANSIMS is an activity-based microsimulation model (Los Alamos National Laboratory, 1998). Individual activity-based travel demands were developed based on US Census data. Specific trip routing plans are developed to satisfy activity desires for individual travelers. Then, individual movements are simulated in the network. The outputs include summaries of individual vehicle movement data second by second. The model is still under development.

- DYNASMART, a dynamic traffic assignment-simulation model, is an intelligent transportation system (ITS) design, planning, and evaluation tool (University of Texas at Austin, 2000*a*). Individual vehicle activity is modeled at a resolution of 6 seconds. The effects of advanced traffic management system (ATMS) strategies, trip chaining, driver classes, geometric and operational restrictions, mode fixed schedule, and capacity changes can be explicitly simulated. The model is not limited by the network size, and satisfies most key physical properties and spatial and temporal constraints pertaining to vehicles, traffic, and highway networks, such as the link flow conservation equations, the FIFO rule, and the vehicle speed-density relationship.

In recent years, there has been a gradual shift toward the use of microsimulation models. All of the above microsimulation models, with individual vehicle travel data at second-by-second resolution, can generate appropriate transportation data for emissions estimates. The differences between the models lie in the type of trip/activity assignment algorithm used and the traffic rules the models follow. The microsimulation models using the dynamic traffic assignment algorithms are considered to be currently feasible for implementation. Among these dynamic traffic assignment microsimulation models, only DYNASMART has the capability for simulating large networks. The model is designed to replicate most real-world traffic situations and provides the detailed vehicle activities required by emissions inventory models. It also achieves a balance between representational detail, computational efficiency, and input/output data sizes.

2.2 Emissions Rates Models

Emissions rates models provide estimates of the rates at which different pollutants are emitted by various types of vehicles. The emissions rates models can be classified into two types[2]:

- Speed-based emissions rates models, and
- Modal-based emissions rates models.

The currently approved emissions rates models, such as EMFAC (from CARB) and MOBILE (from USEPA), are both trip speed-based models. The speed-based models have two major shortcomings (Guensler, 1993):

- The models are based on the Federal Test Procedure (FTP) cycle, which doesn't sufficiently replicate real-world traffic conditions. The FTP cycle was developed over two decades ago and does not include events such as driving at speeds in excess of 57 mph and acceleration rates above 3.3 mph-s. Detailed development of the FTP cycle is addressed by Austin *et al.* (1993).
- The models statistically smooth the effect of acceleration and deceleration (Barth *et al.*, 1996).

Alternatively, modal-based emissions rates models, which are based on the vehicle physical operating parameters, are being developed to capture the effects of acceleration/deceleration. However, most of these models are still in the development stage. Both types of emissions rates models are discussed in the next few sections.

2.2.1 Speed-Based Emissions Rates Models

The speed-based emissions rates models incorporate an extensive database of measured emissions rates (e.g., based on all vehicles run on the FTP cycle) and a procedure for adapting these rates (e.g., through speed correction factors) to actual on-road operating conditions (Figure 5). The on-road operating conditions include whether the vehicle is in the cold/hot/variable start or running mode, the average trip speed at which the vehicle is moving, the environmental conditions, and

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[2] Singer *et al.* (1996) have developed fuel-based CO emissions rates, but to date these rates have only been proposed as a method for evaluating the current emissions rates.

whether or not any Inspection and Maintenance (I/M) program is planned or in place in the modeling domain.

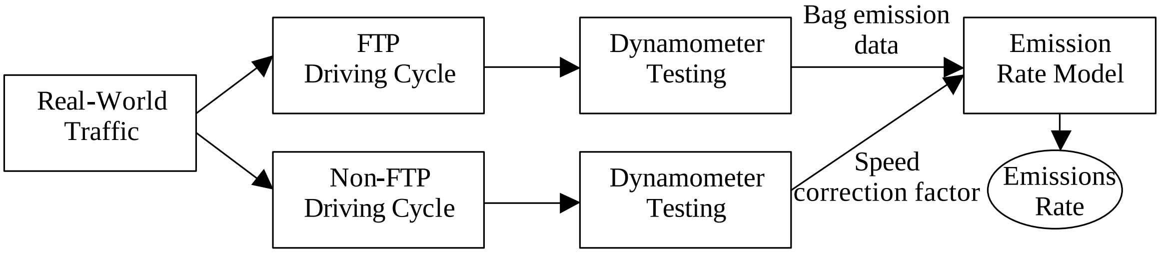

Figure 5. Simplified Process of Speed-Based Emissions Rates Model

EMFAC7G/2000 Model

EMFAC7G (CARB, 1996*b*) is California's current USEPA-approved emissions rates model in CARB's MVEI7G system, which includes WEIGHT, EMFAC7G, REPORT and BURDEN7G. EMFAC7G first corrects base model-year emissions rates (from the FTP cycle) by speed correction factors, temperature correction factors, cycle correction factors and high emitter correction factors. These model-year emissions rates are then multiplied by vehicle population, VMT, and start fractions to produce specific model-year contributions to the fleet composite basic emissions rates. The weighted model year emissions rates are then summed to calculate a single fleet composite basic emissions rates for each combination of variables (process, I/M program, fuel season, vehicle class/tech type, pollutant, speed, and temperature) for a specified calendar year. The resultant composite basic emissions rates are multi-model-year averaged rates.

Two things should be noted for the use of EMFAC7G emissions rates. First, for the light-duty auto (LDA), light-duty truck (LDT), and medium-duty truck (MDT) gasoline vehicles, EMFAC7G calculates start emissions rates as a continuous function of pre-start soak time (1, 5, 10, 20, 40, 60, 90, 120, 180, 300, 480, and 720min) rather than the incremental hot and cold starts methodology of the previous version EMFAC7F. This is known as the variable start methodology. The standard hot/cold start methodology is applied to LDA and LDT diesel vehicles, and motorcycles. Second, running emissions rates are given in thirteen trip speed bins (5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65mph and above). The speed from transportation models is assigned to one of these bins.

Recently, CARB updated EMFAC7G to EMFAC2000 (ver. 2.02). The Unified Cycle (UC), developed to better replicate on road distributions of vehicle speed and acceleration activity, was used to develop the EMFAC2000 emissions rates for light-duty vehicles and medium-duty vehicles. New chassis dynamometer-based heavy-duty diesel trucks (HDDT) emissions rates were developed to replace the engine dynamometer-based HDDT EMFAC7G rates. EMFAC2000 also uses the area-specific activity data to improve the emissions inventory estimate for each geographic area. The changes in EMFAC2000 are expected to improve the accuracy of the on road emissions inventory estimate.

MOBILE5a Model

The USEPA's MOBILE5a (USEPA, 1994; Sierra Research Inc., 1993) is the current USEPA-approved emissions rates model for use outside California. Similar to EMFAC7G, the average base emissions rates derive from vehicle emission tests on the FTP cycle compiled for each model year using a sample of the vehicle fleet. The fleet emissions rate is calculated based on the model-year emissions rates, weighted by the fleet composition for the group for each calendar year. To estimate emissions at operation conditions other than the controlled laboratory testing, base emissions are corrected by applying a variety of statistically derived correction factors (e.g., speed correction, and temperature correction). The major difference between MOBILE5a and EMFAC7G is that MOBILE5a increases the calculated running exhaust emissions rates to include hot/cold start emissions, and thus doesn't need start emissions rates.

2.2.2 Modal-Based Emissions Rates Models

NCHRP Modal Emissions Rates Model

The Center for Environmental Research and Technology at the University of California at Riverside (Barth, 1998, 1999) is developing a comprehensive modal-based emissions rates models for light-duty vehicles, sponsored by the National Cooperative Highway Research Program (NCHRP Project 25-11).

The objective of this research is to predict the instantaneous light-duty vehicle emissions rates as functions of vehicle operation modes. The running exhaust emissions rates are a function of idle, cruise, various levels of acceleration/deceleration, and several other vehicle parameters including engine power, engine speed, air/fuel ratio, fuel use, engine-out emissions, and catalyst pass fraction (An *et al.*, 1997). Start emissions rates are defined by variable vehicle soak time in addition to the vehicle parameters (An *et al*., 1999).

When the model is fully developed, if it is approved by USEPA, can be applied to all levels of transportation/emissions rates interface (Barth, 1998). At the individual vehicle level, the model is expected to work with the microscopic traffic simulation models to predict individual vehicle emissions on a second by second basis. At the link level, link-based activity can be disaggregated into the vehicle level using a modal activity distribution that matches to the vehicle level emissions rates. Skabardonis (1997) has developed a post-processor to disaggregate link-level travel data to modal data using the link characteristics (e.g., facility types and level of service). At the trip and area-aggregated level, emissions from a variety of speed correction factor (SCF) cycles can be measured by this modal-based model. The resulting new SCF curves can then be used to update and improve the standard speed-based emissions rates (Barth, 1997).

Statistical Emissions Rates Model

Georgia Institute of Technology has developed a modeling approach based on statistical distributions of a variety of vehicle technologies and vehicle operating modes (Washington *et al.*, 1997; Wolf *et al.*, 1998). The core of the emissions rates model is based on hierarchical tree-based regression analysis. That is, a statistical procedure iteratively splits a dataset into two parts by selecting a variable that controls the most variability, and determining a cutpoint for that variable that explains the most variability. The result is a tree where each ending node is a set of predictor variable conditions (e.g., vehicle model year, and engine size), and an emissions rate for each pollutant and operating mode. The emission adjustments are based on loads from wind resistance and grade. This model has not undergone peer review.

2.2.3 Discussion on Emissions Rates Models

Currently, modal-based emissions rates models are still very much in development. Only EMFAC and MOBILE are approved by USEPA. Because the speed-based rates are used in conformity implementation, the USEPA and CARB are expending considerable effort in improving them to more accurately reflect real-world vehicle emissions. The trend for improvements of emissions rates models is to predict more detailed speed-based emissions rates at facility level, and finally modal-based emissions rates. Even though there are several problems with current speed-based emissions rates models, the modal-based emissions rates models are not likely to replace them in the near-term future. Although these two approaches differ in terms of spatial and temporal scales, ideally their estimates should be reasonably close to one another.

2.3 Emissions Inventory Models

Total vehicle emissions are calculated in the emissions inventory models. To date, there are two types of models for developing emissions inventories: optimal control theory models, where vehicle emissions are considered a constraint in the target system to be optimized, and transportation and emission interface models, where travel activity data are matched to the appropriate emissions rates to produce emissions estimates. The latter is universally used in conformity analysis.

2.3.1 Optimal Control Theory Model

This type of model is used primarily to study network management strategies, such as managing transportation network to obtain various objectives (e.g., minimize congestion). Producing emissions estimates are not the major purpose of the models. These models formulate various emission concerns (e.g., CO emission ceiling) and traffic conditions (e.g., VMT) as constraints with an objective function to minimize travel costs. Using optimal control theory, an optimal combination of traffic control measures, financial incentives, and road capacity can be found to meet the defined objective while satisfying the emission constraints. This type of model requires extensive input data, and implementation in large urban networks is currently not feasible.

Some more recent studies include a dynamic traffic network model developed to manage congestion, volatile organic compound (VOC) emissions and pavement conditions (Donaghy and Schintler, 1998), a conceptual multi-mode (e.g., auto and transit) traffic network model with emission permits to reduce the travel costs (Nagurney and Ramanujam, 1998), and a microscopic model to find optimal activity trip chaining (minimum activity time) while meeting CO emission constraints (Recker and Parimi, 1999).

2.3.2 Transportation and Emission Interface Models

Transportation and emission interface models combine the transportation activity input from transportation models and emissions rates to directly predict emissions inventories. These models provide a convenient interface between transportation and emissions rates models, and are widely used in the field of mobile sources emissions inventory estimates. The major research efforts in recent years are described below:

- Benson *et al.* (1994) and Knowles *et al.* (1995*b*) developed a series of programs, including a travel demand modeling module and an emissions inventory module, to calculate gridded emissions in Texas. The daily link volumes were seasonally adjusted and then divided by time-of-day factors to hourly volumes. The seasonal adjust factors were estimated using the "1992 Annual Report, Permanent Automatic Traffic Recorders (published by Texas DOT)", and time-of-day factors were developed from the field traffic counts. The resulting hourly volumes were used to re-compute link speeds and VMT in a post-processor. For each hour, MOBILE5a emissions rates were multiplied by VMT for link-based emissions estimates. The gridded emissions were calculated by apportioning link emissions to a grid based on the length of the link falling within the grid. The model was used to develop the 1995 gridded emissions from several freeways in Texas. The unique contribution of this study is the county-specific seasonal adjustment factors. The limitations, however, are that the transportation data (link-based) and emissions rates (trip-based) are not at the same interface level when developing link emissions, and hourly volumes are disaggregated from daily volumes, which is expected to be at best a very rough approximation.

- Taylor and Young (1995) provided a family of models to estimate fuel consumption and vehicle emissions for various analyses using results from a traffic simulation model. The sub-models included an instantaneous model for estimating individual vehicle emissions, an elemental model for developing vehicle emissions at intersections, a running speed model to estimate vehicle emissions along links, and a journey speed model for predicting emissions in a large network. In each sub-model, the emissions rates were defined as the functions of the idle emissions rates and several vehicle physical parameters (e.g., engine efficiency for the instantaneous model). The emissions were computed for each vehicle as the product of emissions rates and vehicle miles traveled. To date, the applications of these sub-models have not been found.

- Ramachandran (1995) developed a microscopic modal emissions inventory model based on the individual vehicle instantaneous modal activity from the microsimulation model DYNASMART. Ramachandran estimated vehicle instantaneous modal emissions as functions of speed and acceleration, predicted by DYNASMART, by operating modes (e.g., acceleration, deceleration, and cruise). These functions were developed based on vehicle dynamometer testing by using the regression analysis performed by Statistical Software Tools (SST). The study contribution is its direct connection to the traffic microsimulation model. However, vehicle modal emissions are also functions of vehicle physical parameters at the modal level, which are not considered in the model. And the emissions rates have not been verified.

- Stopher and Fu (1996) developed a link-based interface model to study the emission impacts of five changes on static travel demand models using daily assignment runs. The first change was to calculate emissions by link, instead of by area using aggregated VMT. They also divided the estimated daily productions and attractions into four time periods before the trip assignment step. The third change was to move the above time-period split right after the trip generation step, then perform trip distribution, mode split, and trip assignment. The fourth change was to apply seasonal adjust factors to adjust the trip tables to summer after the trip generation step. The last change was to use post-processed speeds to replace the travel demand model speeds for emissions estimates.

  The results showed that the area-based emission method underestimated total emissions when compared to the link-based emission method; the time-period split move had little impacts on emission predictions; the summer-adjusted trips produced higher VOC emissions, but lower CO and NOx emissions, and the method using post-processor speeds produced higher VOC, CO, and NOx emissions. This study makes unique contributions in terms of its comparisons of the effects of several possible improvements on emission-specific travel demand modeling. However, the study inappropriately applied the link-based transportation data to trip-based MOBILE5a emissions rates for link emissions development. The summer adjustment factors were estimated from the Nationwide Personal Transportation Survey (NPTS). The impact of using these nationally averaged factors on local areas has not been studied.

- Bell and Kirby (1997) developed a traffic demand management strategy model to improve air quality for urban areas in the UK. The travel demand modeling module included three types of optimization strategies: signal timing, roadway pricing, and mode shift. An emissions inventory model, UROPOL, was used to predict total link emissions for different combinations of strategies. The model was demonstrated in Leicester, UK. However, detailed methodologies of emissions rates derivation were not discussed in their report.

- IMULATE is an integrated model of urban land-use, transportation, energy and emissions estimations used in Canada (Anderson *et al.*, 1996; Scott *et al.*, 1997). It interfaced with TRANSCAD, a GIS system. The link volumes and travel time were measured using a stochastic user equilibrium algorithm. The converged link data were combined with MOBILE5c emissions rates, the Canadian version of MOBILE5a, to compute link emissions. The model was implemented in Hamilton, Canada. The strength of this study is that the land-use model is incorporated in the travel demand model, so that the emission impacts caused by the changes in land-use system can be simulated.

- Gualtieri and Tartaglia (1998) developed a GIS-based model to predict traffic pollutant concentration in Italy. The model included a user equilibrium trip assignment module and an emissions inventory module. The O-D trip matrices were provided by the results of a specially designed experimental travel survey, and emissions rates were based on the average link speeds. The model was implemented on a local network in Firenze, Italy. The GIS mapping ability is the strength of this study, by which vehicle emissions by link can be visually displayed. However, because the O-D matrices from specially designed survey are not easily implementable for a large network, the application of the model is limited.

- MEASURE (Bachman, 1998; Guensler, 1998) is a GIS-based modal emission model developed by Georgia Institute of Technology (Georgia Tech) to measure the air quality impacts for urban and regional transportation policy and development changes. MEASURE works with link modal activity data, converted from the standard four-step travel demand model results, to produce hourly facility-level and gridded vehicle exhaust emission estimates based on modal-based emissions rates, developed by Georgia Institute of Technology. The model was demonstrated using a local network in Atlanta. The GIS mapping ability is the strength of the model. But the method of converting link modal activity data from static travel demand model results and statistical modal-based emission rates have not been validated.

- Ambrosino *et al.* (1999) have developed a comprehensive model to predict fuel consumption and emission impacts for a transportation network under the European Union’s Slam project. The model estimated traffic flows and speeds on each link, then continuously simulated each vehicle movement in a microsimulation module. Fuel consumption and emissions were computed for each link based on the link-level aggregated transportation data from the microsimulator by time period. The distinguishing feature of this study is that link volumes and speeds are aggregated hourly from the microscopic vehicle activity data, which is expected to be more accurate than those from the standard travel demand models. However, the methodology of link-based emissions rates derivation was not discussed in the report.

- Reynolds and Broderick (2000) have developed an emissions inventory model using real-time traffic data obtained from an adaptive traffic control system. The real-time data were aggregated hourly link volumes, vehicle type composition and hourly space-mean link speeds. The link VMTs developed from these aggregated data were multiplied by speed-based emissions rates in UK to compute hourly emissions for each link. The model was implemented at a busy intersection in Dublin, Ireland. Although the real-world monitoring traffic data are more accurate than travel demand models results, they cannot be used to estimate the impacts of proposed new traffic control measures, and application for a large region is not currently feasible.

2.3.3 BURDEN7G/DTIM3 (California)

BURDEN7G (CARB, 1996*d*), developed by CARB, is the California emissions inventory model in the MVEI7G system. DTIM3 (Systems Application International, 1998*a*) has been developed by Caltrans to estimate gridded vehicle emissions for each hour of day. Although it was originally developed to provide input to the urban airshed model, DTIM3 has since been used for inventory predictions (Niemeier and Ito, 2000). These two emissions inventory models are widely used in California. Because the main objective of our study is to develop a new transportation and emission interface model to bridge the gap between them, BURDEN7G and DTIM3 are discussed extensively in Chapter 3.

2.3.4 Discussion on Emissions Inventory Models

As shown in Table 1, with the exception of MEASURE, all of the above models only compute link running exhaust emissions. Start and evaporative emissions are not evaluated in any of the models. A common weakness of most of the models is that the transportation data (link-based) and the emissions rates (trip-based) are not at the same interface level when estimating link emissions. Among other weaknesses are: static travel demand models data are arguably of low accuracy; intrazonal emissions are not included; most models don’t use government-approved emissions rates; and the implementations are not feasible for a large network. Therefore, the emission estimates are highly uncertain, and the models are not appropriate for conformity analysis.

In terms of methodological advantage, Ambrosino (1999) aggregated second-by-second microscopic transportation data to the hourly link-level data and used them with link-based emissions rates in Europe. Although there are problems with his link-based emissions rates, the aggregated link volumes and speeds from the microsimulation model results are specific to each link by hour, which should be more accurate than the volumes disaggregated from daily (or time period) volumes and the multi-hour averaged speeds from travel demand model results. This aggregation methodology, based on the microsimulation models, can improve the accuracy of emission-specific transportation data, and thus result in better emission estimates.

The seasonal adjustment factors proposed by Benson (1994), Knowles (1995*b*), and Stopher and Fu (1996) are another contribution. While Benson and Knowles adjusted link volumes by the link-specific seasonal adjustment factors, Stopher and Fu applied the summer adjustment factors to trip productions and attractions right after the trip generation step within the standard four-step travel demand modeling process. Although the impacts of these two types of adjustments are hard to compare at this point, it’s expected that the adjustment to trip productions and attractions is easier in the real-world applications as modelers don’t need to develop factors for every modeling link.

Table 1. Summary of Current Studies on Transportation and Emission Interface Models

Model	Transportation Data Source	Emissions Rate	Emissions Rate Source	Interface	Application	Limitation
Benson (1994) Knowles (1995*b*)	Static	Speed-based	MOBILE5a	Link-trip	Link emissions	Running exhaust emissions only; Converted hourly volume from daily volume.
Taylor (1995)	Microsimulation	N/A	f(speed, acceleration, vehicle parameters)	Individual vehicle level	Individual vehicle emissions	Running exhaust emissions only; Not feasible for large network.
Ramachandran (1995)	Microsimulation	Modal-based	f(speed, acceleration)	Individual vehicle level	Individual vehicle emissions	Running exhaust emissions only
Stopher and Fu (1996)	Static	Speed-based	MOBILE5a	Link-trip	Link emissions	Running exhaust emissions only
Bell (1996)	Static	N/A	N/A	N/A	Link emissions	Running exhaust emissions only
IMULATE (1997)	Static	Speed-based	MOBILEc	Link-trip	Link emissions	Running exhaust emissions only
Gualtieri (1998)	Static	Speed-based	f(speed)	N/A	Link emissions	Running exhaust emissions only
MEASURE (1998)	Converted from static	Modal-based	Hierarchical tree-based regression analysis	Link-link	Link emissions	Running exhaust emissions and starts emissions only; Transportation data and emissions rates are not validated
Ambrosino (1999)	Microsimulation	N/A	N/A	N/A	Link emissions	Running exhaust emissions only
Reynolds (2000)	Real-time	Speed-based	Ratio to emissions rates at the speed of 30km/hr	N/A	Link emissions	Running exhaust emissions only; Not feasible for large network.

2.4 Conclusion

From the above reviews, there are a few clear trends for developing transportation models, emissions rates models, and emissions inventory models in terms of emissions estimations:

- Transportation Models: Considering the computation efficiency, standard four-step model is universally accepted as a tool to prepare activity input for emissions inventory analysis. The combination of dynamic assignment models and microsimulation models can significantly improve the accuracy of transportation data. The implementation is feasible for both local and large area networks.
- Emissions Rates Models: Currently, speed-based emissions rates are still widely used for inventory analysis. The emissions rates are shifting from speed-based to more detailed facility-specific speed-based rates, and over time may shift to modal-based emissions rates. Modal-based emissions rates will have the ability to be implemented in all the transportation-emissions rate interface levels. However, there are serious limitations which still must be overcome. These two types of emissions rates models should produce consistent results.
- Emissions Inventory Models: Transportation and emission interface models are widely used to predict transportation facility related emissions inventories. The transportation data and emissions rates should reside at the same interface level to be methodologically sound, such as matching the link-based transportation data to link-based emissions rates as opposed to trip-based emissions rates. However, it is important to note that the emissions rates must be approved by the government.

These trends provide a guide in the development of a new interface model to overcome the weaknesses of the models discussed in Section 2.1.1, Section 2.1.4, Section 2.2.3, and Section 2.3.4. The next chapter will analyze the current methodologies used in BURDEN7G and DTIM3, the two interface models currently accepted for use in California. Their respective strengths and weaknesses provide insight and invaluable knowledge for the development of the new model.

CHAPTER 3. ANALYSIS OF CURRENT METHODOLOGY

This chapter is devoted to developing a better understanding of the methodologies of the most widely used inventory models in California (CARB's BURDEN7G[3] and Caltrans's DTIM3). The discussion includes a description of:

- The model structures,
- The transportation input data,
- The transportation data manipulations,
- The inventory calculations and results, and
- The advantages and disadvantages of the modeling methodologies.

These issues touch at the heart of methodology for developing emissions estimates, and provide invaluable suggestions for the development of the new interface model.

3.1 BURDEN7G

BURDEN7G (CARB, 1996*d*), the CARB's vehicle emissions inventory model, is part of the MVEI7G modeling suite. It computes emissions inventories by county for a day, by six time periods (12pm to 6am, 6am to 9am, 9am to 12am, 12am to 3pm, 3pm to 6pm, and 6pm to 12pm). As the last program in the modeling suite, BURDEN7G has four inner loops[4]: county loop, time-period loop, vehicle class loop, and vehicle technology loop. Figure 6 shows the loop orders and program locations.

The other programs included in MVEI7G are WEIGHT, EMFAC7G, and REPORT. WEIGHT is the activity-weighting model, and EMFAC7G produces the fleet composite basic emissions rates. REPORT summarizes the emissions rates by county and air basin. Also in MVEI7G, there is a subroutine ACTSPLT dividing the daily vehicle-class specific transportation activity data (number of vehicles, VMT, and number of starts) for a particular county into six time periods.

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[3] In the latest EMFAC2000, BURDEN is no longer a stand-alone module in the system. Its emissions calculation methodologies are integrated into the system, and processed together with the development of emissions rates and area-specific activity data to estimate emissions inventory. Its emissions estimate formulas stay the same as BURDEN7G.

[4] In programming, loop is a repetition within a program. Whenever a process must be repeated, a loop is set up to handle it. A program has a main loop and a series of minor loops, which are nested within the main loop. (source: http://www.techweb.com/encyclopedia accessed: May 8, 2000)

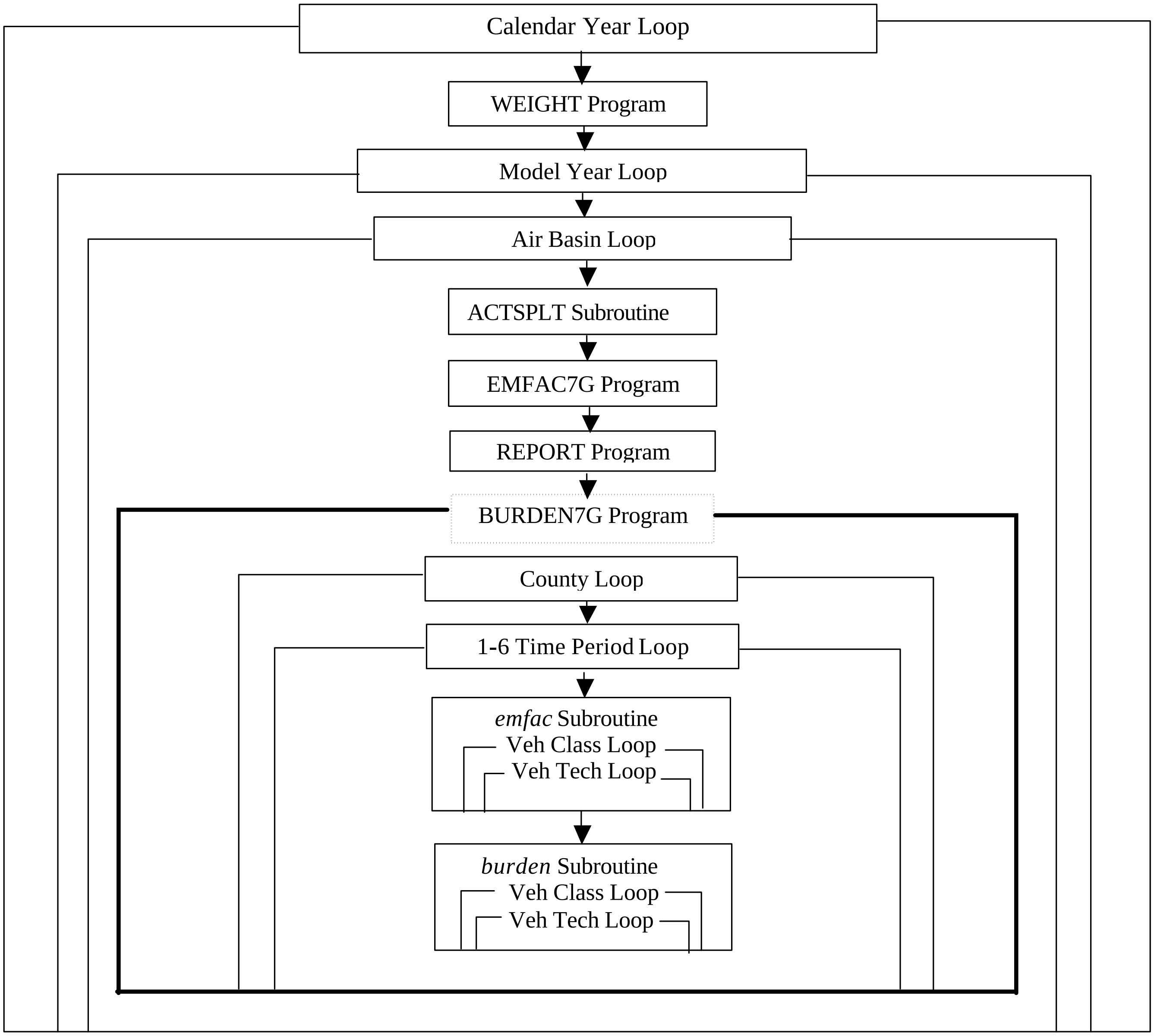

Figure 6. Simplified MVEI7G Model Layout

As shown in Figure 6, *emfac* and *burden*[5] are two subroutines inside BURDEN7G under the county loop and time-period loop. The two lowest inner loops, vehicle class and vehicle technology loops, are in each of these two subroutines. *emfac* prepares the final composite

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[5] *emfac* and *burden* are two subroutines inside the BURDEN7G program. They differ from EMFAC7G and BURDEN7G, which are the emissions rates model and the inventory model respectively in MVEI-7G.

emissions rates based on the basic emissions rates from EMFAC7G. These final emissions rates are passed to *burden* to develop the emissions inventories. Because emissions are actually calculated inside the vehicle technology loop, the transportation input data must be disaggregated into a vehicle class/technology group, which are defined in Table 2. The transportation data processing is discussed next.

Table 2. Definition of Vehicle Class/Tech Group (EMFAC7G)

Light Duty Auto - Catalyst	Light Heavy Duty Truck - Catalyst
Light Duty Auto Non -Catalyst	Light Heavy Duty Truck - Non-Catalyst
Light Duty Auto - Diesel	Light Heavy Duty Truck - Diesel
Light Duty Truck - Catalyst	Medium Heavy Duty Truck - Catalyst
Light Duty Truck Non - Catalyst	Medium Heavy Duty Truck - Non-Catalyst
Light Duty Truck - Diesel	Medium Heavy Duty Truck - Diesel
Medium Duty Truck - Catalyst	Heavy Duty Truck - Diesel
Medium Duty Truck Non - Catalyst	Urban Bus - Diesel
Motorcycle Non - Catalyst	

3.1.1 Transportation Data Processing

BURDEN7G takes the fleet composite basic emissions rates from EMFAC7G and applies them to county-specific transportation data to produce emissions inventories for each county. Input transportation data for BURDEN7G are:

- TRAVEL[6] fractions (provided by WEIGHT),
- County-specific vehicle-class population, VMT, and number of starts (User input),
- County-specific vehicle-class VMT percent by time period (provided by ACTSPLT),
- County-specific vehicle-class starts percent by time period (provided by ACTSPLT),
- Vehicle-class VMT by speed distribution for a time period for a county (User input), and
- Vehicle-class starts by soak time distribution for a time period for a county (User input).

TRAVEL Technology Fractions

WEIGHT (CARB, 1996*c*) generates three types of output:

- Cumulative mileages by model year for each of the vehicle class/technology groups,
- TRAVEL fraction by model year, and
- TRAVEL fraction by vehicle class/tech group.

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[6] The term “TRAVEL” refers to vehicle population, VMT, and numbers of starts.

The cumulative mileages, and TRAVEL fractions by model year which account for the vehicle activity differences by model year, are prepared as input to EMFAC7G in order to calculate the fleet composite basic emissions rates. While these composite basic emissions rates from EMFAC7G are specific to a vehicle class and technology (e.g., LDA-NCAT, LDA-CAT[7]), the transportation data is specific to only a vehicle class (e.g., LDA) for each county. Therefore, the technology fractions (NCAT, CAT, and DSL) of vehicle population, starts, and VMT for each vehicle class are provided by WEIGHT for each county to split vehicle class-based transportation data into technology groups.

County-Specific Vehicle-Class Activity by Time Period

ACTSPLT (CARB, 1996*d*, 1996*e*), a subroutine called after WEIGHT, divides the daily vehicle-class specific transportation data (vehicle population, VMT and number of starts) for a county into six time periods. The input and output data are shown in Table 3.

Table 3. Input and Output in ACTSPLT

Input Activity Data	Output Activity Data
Calendar year	Calendar year
Air basin ID	Air basin ID
County ID	County ID
Vehicle class	Vehicle class
Daily vehicle population by vehicle class	Daily vehicle population by vehicle class
Daily VMT by vehicle class	VMT by vehicle class for a period
Daily number of starts by vehicle class	Number of trips by vehicle class for a period
Percent VMT by vehicle class for a period	
Percent starts by vehicle class for a period	

Vehicle Population: The daily vehicle population (e.g., the number of vehicles in use) by vehicle class is used in BURDEN7G to estimate the emissions from partial and multiple day diurnal breathing and resting loss from gasoline vehicles. Vehicle population estimates are derived from Dept. of Motor Vehicle (DMV)'s annual vehicle registration report, published by DMV's Budget Section. Vehicle population is not broken down into time periods, because population-based diurnal and resting loss emissions are adjusted for the numbers of hours in each period (see Section 3.1.2.2).

VMT and Period Percentages: The daily vehicle miles traveled (VMT) data by vehicle class are used in BURDEN7G to estimate emissions from running exhaust process and running loss

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[7] LDA: Light-duty autos. NCAT: Non-catalyst converter. CAT: Catalyst converter. DSL: Diesel powered technique.

process. Generally, estimates of daily VMT by county are obtained from the Caltrans Motor Vehicle Stock, Travel and Fuel Forecast (MVSTAFF) report. Caltrans projections are generally used for the years beyond the historical data. Local data from travel demand models are preferred if available and appropriate.

VMT estimates are apportioned to each of the six periods of day using information from the Caltrans Statewide Travel Survey, or local travel demand model/survey data if available. These period split fractions are held constant in the future, unless provided by the MPOs in their modeling progress.

Vehicle Starts and Period Percentage: Vehicle starts are used to calculate emissions from starts and hot soaks. Daily vehicle starts are provided for a county, by vehicle class groups. They are organized into different time period by the time-period specific start percent. Both data are provided by the CARB staffs. The sample transportation activity data are shown in Table 4.

Table 4. Sample of Transportation Activity Data File in BURDEN7G

Year	Air Basin	County Code	Vehicle Class	Activity Data		
				Population	**VMT**	**Trips**
1987	NEP	47	6	Urban bus		
1987	NEP	47	7	Heavy duty gas truck		
1987	NEP	47	8	Heavy duty diesel truck		
1987	NEP	47	9	Not used		
1987	NEP	47	10	Motorcycle		
1987	SC	19	1	Light duty autos		
1987	SC	19	2	Not used		
1987	SC	19	3	Not used		
1987	SC	19	4	Light duty trucks		
1987	SC	19	5	Medium duty trucks		
1987	SC	19	6	2166	85836	0
1987	SC	19	7	138101	652894	186904
1987	SC	19	8	6650	549174	0

Source: CARB, 1996*d*. Note that the data have been removed from the first 10 lines to provide the key to the vehicle class codes. County codes are assigned alphabetically (e.g., Alpine = 1, Yuba = 58).

VMT by Speed Distribution

VMT by speed bin distributions (5mph, 10mph, …, 65mph) by vehicle class, which are specific to each of the six time periods for a county, describe the traffic conditions of a region. These distributions are usually derived from travel demand model results. A sample of the file is shown in Table 5. In the absence of local travel demand model data, VMT by speed distributions are developed from the Highway Performance Monitoring System (HPMS) database, maintained by Caltrans.

Start by Soak Time Distribution

Similar to VMT by speed distribution, BURDEN7G uses variable start methodology for LDA, LDT, and MDT gasoline vehicles. That is, the multiple pre-start soak times will be matched to a start emissions rate at each of the times to calculate vehicle start emissions for the inventory. The pre-start soak times are defined as:

RANGE	MID-POINT
Less than 2.5 min	1 minute
2.5 min to 7.5 min	5 minutes
7.5 min to 12.5 min	10 minutes
12.5 min to 27.5 min	20 minutes
27.5 min to 47.5 min	40 minutes
47.5 min to 72.5 min	60 minutes
72.5 min to 107.5 min	90 minutes
107.5 min to 137.5 min	120 minutes
137.5 min to 227.5 min	180 minutes
227.5 min to 373.5 min	300 minutes
373.5 min to 587.5 min	480 minutes
Greater than 587.5 min	720 minutes

A single California representation of pre-start soak time percentages provided by CARB is used until regional specific differences can be established through more extensive instrumented vehicle studies.

Table 5. Sample of VMT by Speed Distribution File in BURDEN7G

Air Basin	County ID	Year	Vehicle Class	Speed 5	Speed 10	Speed 15	Speed 20	Speed 25	Speed 30	Speed 35	Speed 40	Speed 45	Speed 50	Speed 55	Speed 60	Speed 65
GBV	20	2020	1	0.7880	0.7880	1.5760	3.1520	3.6520	5.1520	8.2880	18.6360	24.0600	22.7720	7.4240	3.7120	0.0000
GBV	20	2020	9	0.0000	1.9800	2.9700	3.9600	6.9310	9.4060	10.3960	10.8910	13.8610	13.3660	15.3470	10.8910	0.0000
GBV	140	2020	1	1.0145	1.0145	2.0290	4.0580	4.5825	6.1560	5.8255	6.7595	8.7720	9.0445	15.3565	17.5185	16.8690

Source: CARB, 1996*d*.
(Speed Unit: mph)

3.1.2 Emissions Inventory Methodology

BURDEN7G prepares three types of emissions: running exhaust and start emissions, and evaporative emissions. A BURDEN7G emission estimate is the product of a composite emissions rate multiplied by the appropriate transportation data from WEIGHT and ACTSPLT. In the daily time-period loop, BURDEN7G will specify a summer or winter inventory, and then the program will execute two subroutines – *emfac* and *burden*. As we already discussed before, *emfac* prepares the final fleet composite emissions rates for *burden*, where emissions inventories are calculated. Through these fleet composite emissions rates, *burden* can simply multiply these emissions rates by the total fleet transportation activity data to produce emissions for each county.

Running Exhaust Emissions and Start Emissions

Running exhaust emissions occur when vehicles are running stabilized on a roadway due to combustion. Start emissions account for emissions during the first few minutes of vehicle operation. For composite running exhaust emissions rates, the VMT distribution is multiplied by the associated running exhaust emissions rate at each speed group to account for the contribution of different speeds to the composite running exhaust emissions rates (Equation 1). For composite start emissions rates, the start distribution by soak time is multiplied by the related start emissions rates to account for the different soak time before vehicles are started (Equation 2). The weighted emissions rates are summed over all the speed groups or the soak bins for a vehicle class/tech group. These composite emissions rates are calculated for each county by period for a specific vehicle class/tech group in *emfac*. Then inventories are computed by multiplying the vehicle class/tech specific composite emissions rates by the time-period VMT or starts for a vehicle class/tech group in *burden* (Equation 3).

$$CEF = \sum_{n=1}^{13} \frac{R(n) \times EF(n)}{RSPEED(n)} \qquad \text{-------- Equation 1}$$

where

CEF = Composite running exhaust emissions rates
R(n) = VMT by speed distributions
EF = Composite basic emissions rates for running exhaust from EMFAC7G
RSPEED = Value of speed bins
n = Number of speed bins (1, 2, …, 13)

$$CEF = \sum_{n=1}^{12} (R(n) \times EF(n)) \qquad \text{------------} \quad \text{Equation 2}$$

where

CEF = Composite start emissions rates
R(n) = Start by soak time distributions
EF = Composite basic start emissions rates from EMFAC7G
n = Number of soak time bins (1, 2, …, 12)

$$RE = CEF \times VMTorStart \qquad \text{------------} \quad \text{Equation 3}$$

where

RE = Total Emissions (running exhaust or start)
CEF = Composite emissions rates (running exhausts or starts) from *emfac*
VMT = Vehicle miles traveled
START = Number of vehicle starts

Evaporative Emissions

BURDEN7G calculates four types of evaporative emissions – hot soak, diurnal, resting loss, and evaporative running loss emissions. Hot soak emissions are defined as hydrocarbon vapors that are emitted within one hour after a vehicle driven in a stabilized mode and then shut off. Not all trips end in a complete hot soak. Diurnal emissions are caused by the temperature increase during a day when parked. On the other side, resting loss emissions are evaporative emissions that occur when a vehicle is at rest, and the ambient temperature is declining, or constant. Both diurnal and resting loss emissions are modeled as having two components: partial day emissions, and multiple day emissions. Running loss emissions occur due to vehicle gasoline vapor loss while vehicles are running stabilized.

In daily time-period loop, the default percentages of the vehicle fleet experiencing hot soak (HTSKPCT), partial diurnal (DRNLPCT), and partial resting loss (RSTGPCT) are given by time periods, respectively (Table 6). The whole fleet is assumed to experience the evaporative running loss. BURDEN7G assumes all vehicles experience both multi-day diurnal emissions and multi-day resting loss emissions in a day.

Table 6. Default Percent of Vehicle Fleet Experiencing Parks Emissions During a Period

Time Period	1	2	3	4	5	6
HTSKPCT	0.7520	0.6631	0.5594	0.5731	0.6074	0.6861
DRNLPCT	0.77	0.661	0.623	0.594	0.578	0.723
RSTGPCT	0.77	0.661	0.623	0.594	0.578	0.723

Source: CARB, 1996*d*.

For hot soak emissions, hot soak emissions rates are multiplied by vehicle percentage and number of starts by period to produce hot soak emissions (Equation 4).

$$HTSK = (CEF \times HTSKPCT \times TRIP) \qquad \text{-----------} \quad \text{Equation 4}$$

where

HTSK = Hot soak emissions

CEF = Hot soak emissions rates from EMFAC7G

HTSKPCT = Percent of trips during a time period ending in a complete hot soak

TRIP = Number of starts/day

Equation 5 is used to calculate diurnal evaporative emissions. Partial-day diurnal emissions rate (POLL8) is temperature corrected by diurnal temperature correction factor and the multi-day rate (POLL1) is divided by 24 to yield a "hourly" rate. These rates are combined and then multiplied by the number of hours of that period and the number of vehicles to generate diurnal emissions for a period. The temperature correction factor is defined by the begin/end temperatures of that period, and season of interest. Equation 6 shows how the temperature correction factor is calculated.

$$DRNL = (((POLL8 \times DRNLTCF \times DRNLPCT) + \frac{POLL1}{24}) \times hours) \times VEH \qquad \text{------} \quad \text{Equation 5}$$

$$DRNLTCF = \frac{E^{a \times B} \times (E^{C \times Temp_{end}} - E^{C \times Temp_{begin}})}{E^{b \times B} \times (E^{C \times 84} - E^{C \times 60})} \qquad \text{------} \quad \text{Equation 6}$$

where

DRNL = Diurnal emissions

POLL8 = Partial-day emissions rates from EMFAC7G

DRNLTCF = Diurnal temperature correction factor

DRNLPCT = Default percentage of vehicles experiencing a diurnal

POLL1 = Multi-day emissions rate from EMFAC7G

hours = Number of hours in the period being calculated

VEH = Daily total number of vehicles

B = 0.2357

C = 0.0409

a and b = constant varying by the calendar year and season of interest

Resting loss emissions are determined by an equation similar to Equation 5, except that temperature correction is not needed. In terms of running loss emissions, the same equation (Equation 3) is used.

3.1.3 Discussion on BURDEN7G Methodology

BURDEN7G has two major weaknesses. This first is that BURDEN7G doesn't have a direct connection to travel demand models. As shown in Table 7, a day is divided into six time periods. For each period, users must prepare VMT and start percentage input, a VMT by speed distribution, and a start by soak time distribution. Some of the county-scale data (e.g., start and start distribution) are usually provided by the state or local agencies. Users don't have enough flexibility to update these activity inputs. The transportation data (e.g., link volume, link speed, and distance) produced by travel demand models must be post-processed to the appropriate format (e.g., daily VMT, period percent, and VMT distribution) for use in BURDEN7G.

Table 7. Sources for the Activity Data and Their Uses in BURDEN7G

Activity	Sources	Usage in Calculation
Daily Vehicle Population	DMV	Diurnal Emission, Resting Loss
Daily VMT and Period Percent	Caltrans, Regional Transportation Planning Agencies (travel demand model)	Running Exhaust Emission, Running Evaporation
Daily Vehicle Start and Period Percent	USEPA, Caltrans, CARB	Start Emission, Hot Soak Emission
VMT by Speed Distributions	Caltrans, Regional Transportation Planning Agencies (travel demand model)	Composite Running Emissions Rate
Start by Soak Bin Distributions	CARB	Composite Start Emissions Rate

The second weakness is that BURDEN7G estimates emissions on a macroscopic scale. Emissions are calculated by multi-hour time periods for a county. Users cannot compute hourly gridded emissions for the dispersion models. Also, BURDEN7G cannot be used to spatially and temporally evaluate vehicle emissions, thus limiting BURDEN7G's implementation.

Alternatively, the BURDEN7G methodology has many strengths:

- It is computationally very efficient;
- The VMT by speed distribution methodology and start by soak time distribution methodology, aggregating link traffic conditions and variable starts to a regional scale, provides an efficient method to compute emissions;
- The model's aggregated transportation data and emissions rates both sit at a regional interface level. This ensures that emission estimates from BURDEN7G are methodologically sound; and
- The model uses a set of USEPA-approved emission formulations.

These strengths will provide an important reference point for the new model development discussed in Chapter 4.

3.2 DTIM3

The DTIM3 model, including sub-programs *convirs*, *irs3* and *dtim3*[8], was developed by Caltrans to enhance vehicle emission forecasting tools. The model was originally developed to provide detailed emissions input for photochemical grid models such as the Urban Airshed Model, but has since been used to estimate regional vehicle emissions (Niemeier and Ito, 2000). The DTIM3 model calculates gridded emissions based on detailed transportation information from the standard four-step travel demand models for each link by hour of day. This approach produces emissions inventory that (1) provide information on the spatial and temporal emissions distribution, and (2) can show the emissions difference for certain types of transportation alternatives (Systems Application International, 1998*a*).

The structure of the DTIM3 model is shown in Figure 7. Two sub-programs (*convirs* and *irs3*) prepare emissions rates for *dtim3*. *Convirs* reformats fleet basic composite emissions rates from EMFAC7G. *Irs3* produces fleet average emissions rates. These emissions rates are then multiplied by the link-based vehicle activity estimates provided by travel demand models to calculate vehicle emissions in *dtim3*. Thus, the DTIM3 model connects output from commonly used travel demand models (e.g., MINUTP and TRANPLAN) directly to emissions inventory calculations. An option available in *dtim3* is a speed post-processor algorithm, which can calculate hourly speeds by roadway link. These speeds can be then used in place of speed output from the travel demand models, which often do not reflect the actual level of congestion on a roadway link.

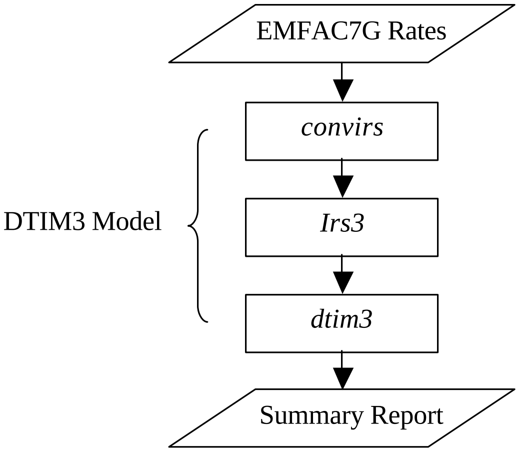

Figure 7. The Structure of the DTIM3 Model

3.2.1 Preparation of Emissions Rates

EMFAC7G contains summer and winter emissions rates both with and without the effects of state vehicle inspection/maintenance (I/M) programs. They are specific to a vehicle class/tech group for diurnal evaporate, resting loss evaporate, hot soak evaporate, starts, running exhaust or loss for a calendar year. Only the emissions rates meeting the user's specifications (e.g., calendar year and I/M program) are imported to *convirs*. To match the format of transportation data, *convirs* converts multi-day diurnal and resting loss from daily rates to hourly rates by dividing by 24 (hours). EMFAC7G hot soak rates (grams per trip) are considered as grams per hour of hot soak. The partial day diurnal rates are corrected by the Reid Vapor Pressure correction factor (Equation 7). The unit of running emissions rates is grams per hour and the unit of start is grams per start (Systems Application International, 1998*b*). The units of these emissions rates are summarized in Table 8.

$$rvpcf = \frac{\exp(0.2357 \times a)}{\exp(0.2357 \times 9)} \qquad \text{------------ Equation 7}$$

where

a = 9.0 if calendar year <1992 and season is summer
= 11.7 if calendar year <1992 and season is winter
= 7.8 if 1992 =< calendar year <1996 and season is summer

---

[8] In this proposal, the lowercase single term "*dtim3*" refers to the *dtim3* sub-program only, which is inside the DTIM3 model noted by an uppercase term.

= 10.0 if 1992 =< calendar year <1996 and season is winter
= 7.0 if calendar year >= 1996 and season is summer
= 9.0 if calendar year >= 1996 and season is winter

Table 8. EMFAC7G Emissions Rates and Their Units in the DTIM3 Model after Conversion

Process	Unit of EMFAC7G Rates	Unit in DTIM3
Diurnal evaporate	Multi-day: grams/day Partial day: grams/hour	Multi-day: grams/hour Partial day: grams/hour
Resting loss evaporate	Multi-day: grams/day Partial day: grams/hour	Multi-day: grams/hour Partial day: grams/hour
Hot soak evaporate	Grams/trip	Grams/hour hot soak
Starts	Grams/trip	Grams/start
Running exhaust and loss	Grams/hour	Grams/hour

The converted emissions rates are passed to *irs3*. *Irs3* combines emissions rates for each vehicle class/tech group into composite fleet average emissions rates using specifications of technology mix by vehicle class (Equation 8). The input data for *irs3* are:

- Vehicle mix (user input),
- Vehicle technology weights for each vehicle class (from EMFAC7G), and
- Technology to species correspondence (user input).

In *irs3* options file, the user can define fleets by setting up the vehicle class mix (VMT.MIX) for each fleet. The row of VMT.MIX is composed of vehicle-class specific travel weights. This allows users to simulate emissions rates for various single vehicle-class fleets and multi-vehicle class fleets. Technology to species correspondence (TEC.SPC) is used to map different pollutants by vehicle technology type for a subset of pollutant emission rates. This enables users to calculate the technology-specific emissions for the pollutants of interest. Table 9 is a typical input format.

Table 9. Sample Input in *irs3*

			LDA	**LDT**	**MDT**	**LHG**	**LHD**	**MHG**	**MHD**	**HHD**	**UBD**	**MCY**
Veh.mix	1	LDA	656									
Veh.mix	2	LDT		285								
Veh.mix	3	MDT			54	32	10	10	10	5	1	4
Tec.spc	TOG	1 2 3										
Tec.spc	EVAP	1 2 3										

Source: Systems Application International (1998*a*). MDT: Medium heavy-duty gasoline trucks. LHG: Light heavy-duty gasoline trucks. LHD: Light heavy-duty diesel trucks. MHG: Medium heavy-duty diesel trucks. HHD: Heavy heavy-duty diesel trucks. UBD: Diesel urban buses. MCY: Motorcycles.

$$EF_{fleet} = \sum_{vc=1}^{10} \left(\sum_{tec=1}^{3} EF_{vc,tec} \times TECWT_{vc,tec} \right) \times VMTMIX_{vc} \qquad \text{-------} \quad \text{Equation 8}$$

where

EF_{fleet} = Fleet average emissions rates

$EF_{vc,tec}$ = Vehicle class and technology specific emissions rates

$TECWT_{vc,tec}$ = TRAVEL fraction for a specific technology type in a vehicle class (from EMFAC7G)

VMTMIX = Fraction of travel for a vehicle class (user input)

vc = Vehicle class

tec = Vehicle technology

3.2.2 Dtim3 Sub-Program

Before discussing the *dtim3* algorithm, the following definitions are necessary:

- MAP files: A format designed for reporting transportation activity for the DTIM model. The information describing the network and travel activity is stored in a column format.
- FWY files: An alternative format designed by Caltrans for reporting transportation activity for use in the mainframe DTIM model. There are two formats. FWY015 files provide the network description, and FWY059 provide actual estimates of travel activity.
- Trip type: Home-based work, home-based others, non home-based trip, *etc.*
- Trip end type: Attraction/production.
- Link travel: Vehicle activity occurring on roadways.
- Intrazonal travel: Vehicle activity occurring within a zone; activity is not modeled explicitly in the transportation model.
- Trip-end travel: Vehicle activity occurring when vehicle is started and parked.

Dtim3 prepares estimates of mobile sources emissions based on the fleet average emissions rates from *irs3* and transportation data from travel demand models. The main program can be divided into two parts (the FWY program or the MAP program) depending on the format of input transportation files (FWY file or MAP file). The flowchart of the main program is shown in Figure 8. For either the FWY or MAP program, the transportation data from travel demand models must be separated into three groups:

- Link data,

- Intrazonal data, and
- Trip-end data.

Both the FWY and MAP programs calculate emissions for these three types of data in the same way. The general algorithm can be defined as three steps:

1) Read input data,
2) Search grid cells, and
3) Calculate emissions in each cell.

At the first step, transportation data are imported from the FWY file or MAP file. At the next step, *dtim3* defines the grid cells by transforming node coordinates to the Universal Transverse Mercator (UTM) coordinates and then calculates the grid cell identifications (ID). Based on the cell ID, *dtim3* performs emission calculations for each cell at the third step.

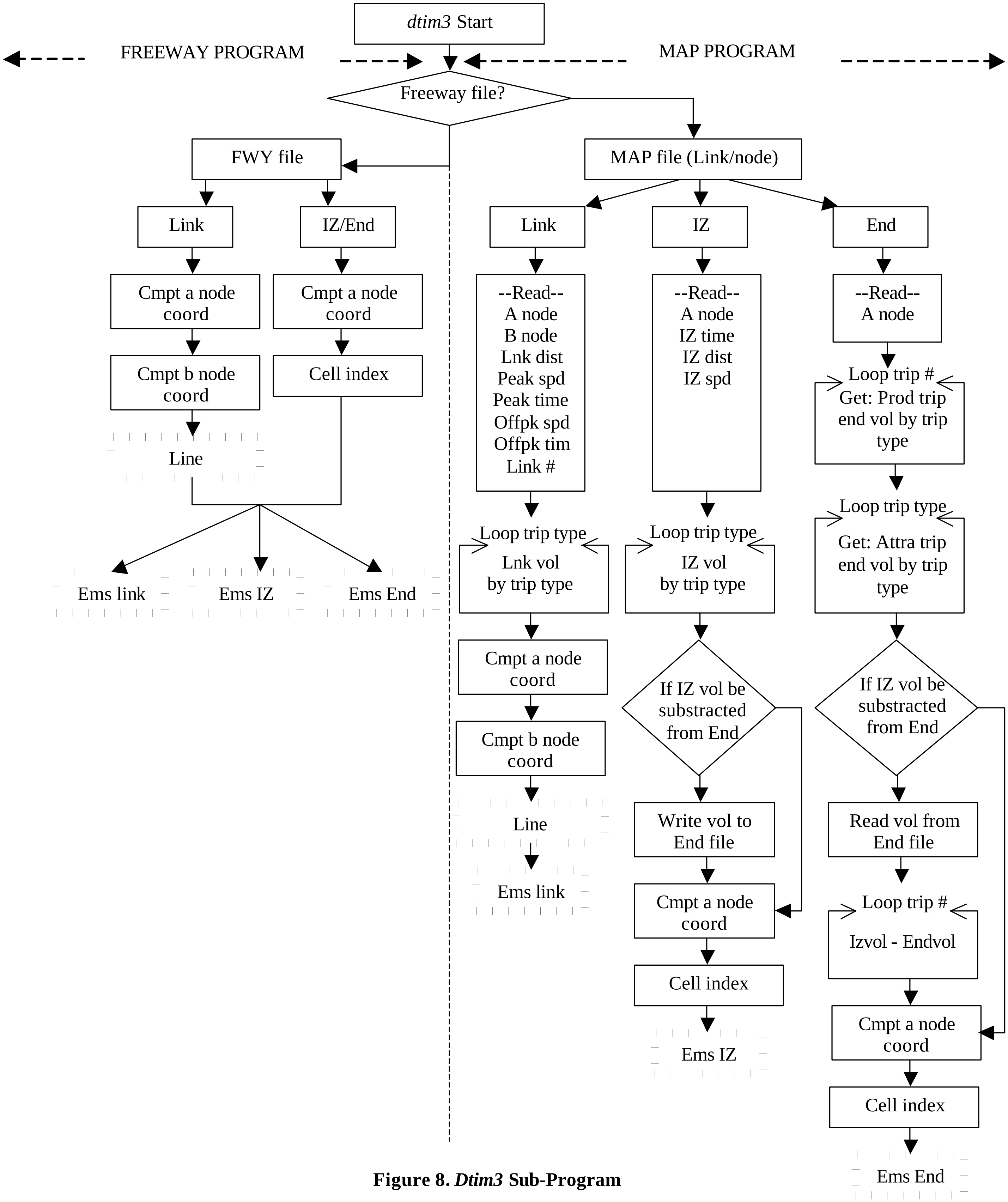

Figure 8. ***Dtim3*** **Sub-Program**

Grid Cell Network

In *dtim3*, emissions are calculated within grid cells, which are a series of cells along a link for link-based trips, or the points where the intrazonal and trip-end trips occur. This section discusses how grid cells are defined for three groups of records (link, intrazonal and trip-end), which will help us understand how to build a cell network for the new interface model.

Link Cell: If trips are link-based, *dtim3* defines the cell ID in the LINE Subroutine. As specified by the travel demand models, each link is defined by two nodes. Input data in LINE are:

- X, Y coordinates of link node (two ends) from travel demand models

Output data are:

- Cell ID, and
- Fraction of the link within the grid cell boundary.

Dtim3 locates grid cells along with each link. First, the user specifies a UTM modeling domain by providing two nodes in the transportation network. The modeling domain is defined by specifying the grid origin, cell width, and number of cells. An example of specification is shown in Table 10. *Dtim3* excludes all links and zones located outside the specified domain from its emission calculations. Thus, only the travel occurring in the remaining links will be considered.

Table 10. Modeling Domain Definition

	X Direction	Y Direction
Grid origin coordinates	552	4162
Cell width (km)	5.	5.
Number of cells	34	36

In the second step, the program will calculate the beginning node UTM coordinates for a link based on Equation 9.

$$\begin{cases} X = a \times trans_x + b \times trans_y + conv_x \\ Y = a \times trans_y - b \times trans_x + conv_y \end{cases} \quad \text{------- Equation 9}$$

where

X, Y = Output UTM coordinate in x or y direction

a, b = Coefficient for translation in x or y direction (user input)

trans = Node coordinate from the input transportation file

conv = Translation conversion factor in x or y direction (user input)

Based on these computed UTM coordinates, LINE locates this link into a cell, and then calculates its cell ID (Equation 10). By using the link slope, current cell's upper boundary Y and right boundary X coordinates, the next two intersections "a" and "b" of the link and grid can be found (Figure 10). The intersection closer to the grid origin is the next link crossing point with the grid. The ratio of link distance in a cell is computed by dividing the cell-portion distance between two crossing points "A" and "a" by its whole link distance. The program repeats the cell ID calculation till the end of the link.

$$\begin{aligned} ic &= (xatemp - xorig) \div \Delta x \\ jc &= (yatemp - yorig) \div \Delta y \\ id &= ic \times 1000 + jc \end{aligned} \qquad \text{-------- Equation 10}$$

where

xatemp	= X coordinate of the beginning node for a link
yatemp	= Y coordinate of the beginning node for a link
xorig	= X origin coordinate of the modeling domain
yorig	= Y origin coordinate of the modeling domain
Δx, Δy	= Cell width
id	= Cell identification number

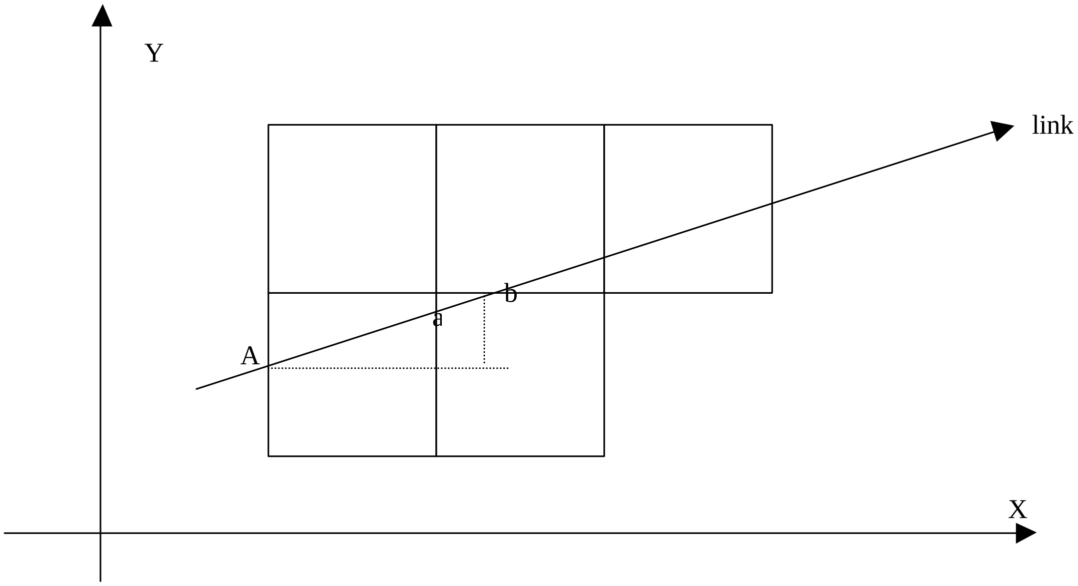

Figure 9. *Dtim3* Grid Mesh Construction Method

Intrazonal or Trip-End Cell: The intrazonal travel activities occur within a TAZ, represented by a centroid. The trip-end travels occur only at one end of a link (a node). *dtim3* allocates the emissions generated from this single centroid/node to either one single cell or multiple cells. The single cell is called the intrazonal or trip-end cell, which represents all the travel activities in the respective zone or trip-end. For this kind of single cell, *dtim3* first calculates its coordinates based on Equations 9, then calculates its cell ID using Equation 10. No distance fraction is needed to calculate in *dtim3* for the intrazonal or trip-end cell.

To allocate trip end and intrazonal emissions to multiple grid cells, an optional Polygon Intersection and Overlay (PIOS) file, providing the percentage of zone in each grid cell, is defined by the user. This zone ratio is applied to VHT in emission calculations. However, the PIOS file is rarely available for a region (Systems Application International, 1998*a*).

The algorithm of LINE Subroutine is shown in Figure 10.

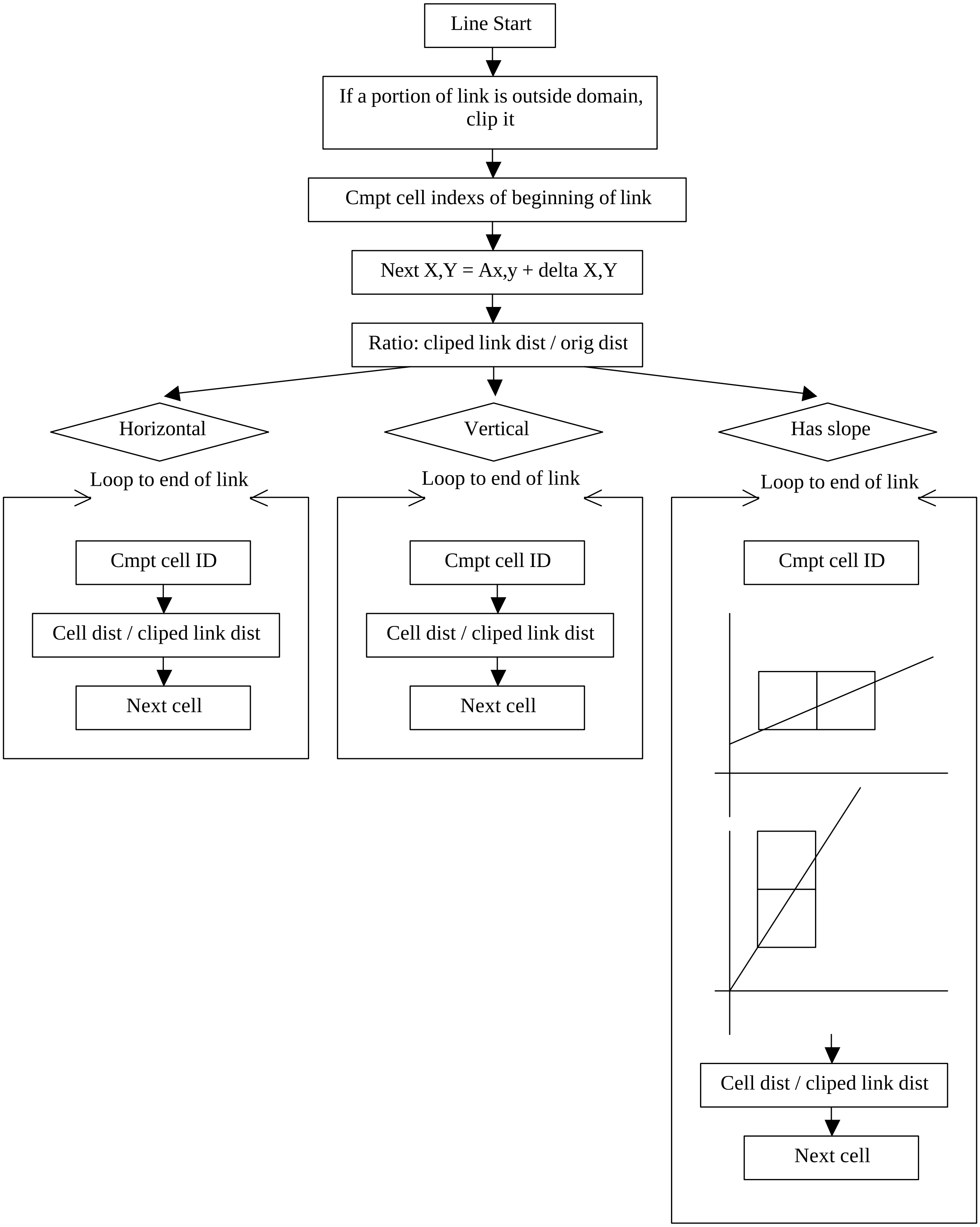

Figure 10. Line Subroutine

Transportation Data and Emissions Inventory Methodology

Dtim3 develops emission estimates separately for these three types of data (link, intrazonal or trip-end data). For each type of data, *dtim3* computes emissions by multiplying activity time by the related emissions rates. If users choose to generate gridded emissions, *dtim3* summarizes the total emissions for each grid cell.

The Starts/Parks/Stables (SPS) file is an input file to *dtim3* that provides key information to disaggregate transportation data by hour of day for each trip type. SPS file maps fleets to facility type, breakdowns starts and parks by hour of day, divides the fraction of cold starts by technology by hour of day, provides the percent of parks resulting in hot soaks and daily diurnal emissions, identifies whether peak or off-peak speeds are to be used for each hour, and provides the fraction of total link-based travel occurring in each hour. The hourly volumes, which are used to compute VHT and volume/capacity ratios, are also specified by SPS file. The SPS data and their usage are listed in Table 11.

Table 11. Activity Input in SPS File and Their Usage in *dtim3*

Activity Input		Usage
Trip type data	Number of trip types	Control trip type loop
	Percent of trip type in this fleet	Compute VHT
Fleet data	Number of different fleets	Control fleet loop
Start data	Percent of starts by hour	Compute start VHT
	Start technology percentage	Control start tech loop
	Start proportions by soak time range	Compute start VHT
Park data	Percent of parks by hour	Compute hot soak and diurnal VHT
	Percent of parks in hot soaks by hour	Compute hot soak VHT
	Percent of park in diurnal by hour	Compute diurnal VHT
Stable data	Fraction of total link-based travel occurring by hour	Compute VHT, V/C ratio
	Flags for stable speed	Decide peak or off-peak

Link Transportation Data and Emission Algorithm: Link-based travel generates running emissions, including running exhaust and running loss (Figure 11). Input data in *dtim3* are:

- SPS file,
- A node, B node and their X,Y coordinates,
- Link volumes from travel demand models,
- Link capacity from travel demand models,
- Peak speed and time, off-peak speed and time from travel demand models,
- Fraction of link length in a cell from LINE subroutine, and

- Link facility type from travel demand models.

Dtim3 reads link volumes by trip types from travel demand models. SPS information is then used to divide volumes by hour of day. The volumes for each hour are used for VHT[9] estimates, which in turn determine vehicle emissions.

Emissions rates are based on vehicle speeds. In *dtim3*, an optional speed processor is provided to replace the speed from travel demand models should the user want to re-compute link speeds based on hourly volume/capacity ratio. The user must specify link facility type, free flow speed, and either total capacity or number of lanes for each link in the network to run the speed processor. Details of the methodology are discussed in Systems Application International (1998*a*).

The computed fraction of link length from the above LINE subroutine is used to compute the VHT in each cell. Link facility types from travel demand models are used to compute fleet speed in the speed processor.

Running emissions (link-based)

The above transportation data are then used in Equation 11. Time for link record is multiplied by the link volume, percentage of trip type of the fleet, and the fraction of total link-based travel occurring in this hour to get the vehicle hour traveled for running emissions. The emissions are calculated by multiplying VHT by the emissions rates in each cell.

$$vht = time \times vol \times trpfrc \times ratio \times stable \qquad \text{------- Equation 11}$$

where

vht = Vehicle hour traveled for running emissions
time = Time for link record
vol = Link volume
trpfrc = Percentage of trip type (e.g., home-based work)
ratio = Link fraction in the cell
stable = Fraction of total link-based travel occurring in each hour

---

[9] *dtim3* produces emissions based on emissions rates (gram/hour) and VHT (hour), instead of VMT (mile).

Intrazonal Transportation Data and Emission Algorithm: All kinds of emissions can occur in intrazonal travel. The algorithm for running emissions is the same as that applied to link emissions. Park emissions are treated as a hot soak, resting loss, or diurnal emissions. Input data in *dtim3* for intrazonal emissions are:

- SPS file,
- Zone node for intrazonal record,
- Intrazonal trip volume (number of trips) by trip-type,
- Time, speed, distance for intrazonal record (at least two of them), and
- Percentage of zone in each cell from PIOS file.

The SPS file specifies the fraction of total link-based travel occurring in each hour, the percentage of trip type in the fleet, the percent of diurnal parks in each hour, hourly percent of starts, hourly start proportions by soak time range, technology type of start record, percent of parks in each hour, and percent of parks in hot soaks in each hour. These data, together with intrazonal volume, zone fraction and time, are used to compute VHT in different emission processes. The algorithm is shown in Figure 12.

1) Running emissions (intrazonal)

These emissions are calculated in the same way as the link emission algorithm. Time for intrazonal record is multiplied by the intrazonal volume (number of trips), percentage of trip type of the fleet, and the fraction of total link-based travel occurring in this hour to get the vehicle hour traveled for running emissions (Equation 12).

$$vht = time \times vol \times trpfrc \times ratio \times stable \qquad \text{-------- Equation 12}$$

where

vht = Vehicle time traveled for running emissions
time = Time for intrazonal record
vol = Intrazonal volume
trpfrc = Percentage of trip type in the fleet
ratio = Zone fraction in the cell
stable = Fraction of total link-based travel occurring in each hour

2) Start emissions (intrazonal)

When calculating start emissions for LDA, LDT, and MDT gasoline vehicles, instead of dividing starts into only two categories (hot and cold), continuous starts are divided into 12 categories based on soak time range. Each range has its own set of start emissions rates. Intrazonal volume (number of trips) by trip-type is multiplied by hourly percentage of starts, hourly start proportions by soak time range, and percentage of trip type in the fleet to compute VHT for start emissions (Equation 13).

$$vht = vol \times trpfrc \times start \times midstt \times ratio$$ ------ Equation 13

where

vht = Vehicle time traveled for start emissions
vol = Intrazonal volume
start = Hourly percentage of starts
trpfrc = Percentage of trip type in the fleet
midstt = Hourly start proportions by soak time range
ratio = Zone fraction in the cell

LDA and LDT diesel vehicles and motorcycles still use hot/cold start emission methodology. The same Equation 13 is used by replacing the value of midstt with hot/cold start percent.

3) Hot soak emissions (intrazonal)

Intrazonal volume by trip-type is multiplied by the percentage of trip type of the fleet, percent of parks in each hour, and percent of parks in hot soaks in each hour to get VHT for hot soak emissions (Equation 14).

$$vht = vol \times trpfrc \times parks \times hotprk \times ratio$$ -------- Equation 14

where

vht = Vehicle time traveled for hot soak emissions
vol = Intrazonal volume
trpfrc = Percentage of trip type in the fleet
parks = Percent of parks in this hour
hotprk = Percent of parks in hot soaks in this hour
ratio = Zone fraction in the cell

4) Partial-day resting loss emissions (intrazonal)

If temperature decreases in the current hour, intrazonal volume by trip-type is multiplied by the percentage of trip type of the fleet and the percentage of diurnal parks in the current hour to get VHT for resting loss emissions (Equation 15). Multi-day resting loss emissions are computed in trip-end algorithm.

$$vht = vol \times trpfrc \times diuprk \times ratio \qquad \text{------- Equation 15}$$

where

vht = Vehicle time traveled for resting loss emissions
vol = Intrazonal volume
trpfrc = Percentage of trip type in the fleet
diuprk = Percent of diurnal parks in this hour
ratio = Zone fraction in the cell

5) Partial-day diurnal emissions (intrazonal)

If temperature increases in the current hour, intrazonal volume by trip-type is multiplied by the percent of trip type of the fleet, percent of diurnal parks and diurnal adjustment factor to get VHT for diurnal emissions (Equation 16). Multi-day diurnal emissions are computed in trip-end algorithm.

$$Diu = vol \times trpfrc \times diuprk \times ratio \times cf \qquad \text{--------- Equation 16}$$

$$cf = \frac{E^{0.0409 \times t_1} - E^{0.0409 \times t_0}}{E^{0.0409 \times 84} - E^{0.0409 \times 60}}$$

where

Diu = Vehicle time travel for diurnal emissions
vol = Intrazonal volume
trpfrc = Percentage of trip type of the fleet
diuprk = Percent of diurnal parks in this hour
ratio = Zone fraction in the cell
cf = Partial-day diurnal adjustment factor
t_0 = Temperature of previous hour
t_1 = Temperature of current hour

Trip-End Emission Algorithm: There are no running emissions occurring in trip-end emissions. The algorithms for start and park emissions, shown in Figure 13, are similar to those in the intrazonal emissions. The only difference is that multi-day emissions are calculated instead of partial-day emissions. Equation 17 is used to replace the partial-day diurnal temperature adjustment factors to calculate VHT in Equation 16, which are based on minimum and maximum temperatures for the entire day, rather than the temperatures of the previous hour and current hour.

$$cf = \frac{E^{0.0409 \times t_{\max}} - E^{0.0409 \times t_{\min}}}{E^{0.0409 \times 84} - E^{0.0409 \times 60}} \qquad \text{-------- Equation 17}$$

where

cf = Multi-day diurnal adjustment factor for trip-end record

t_{min} = Minimum temperature of the day

t_{max} = Maximum temperature of the day

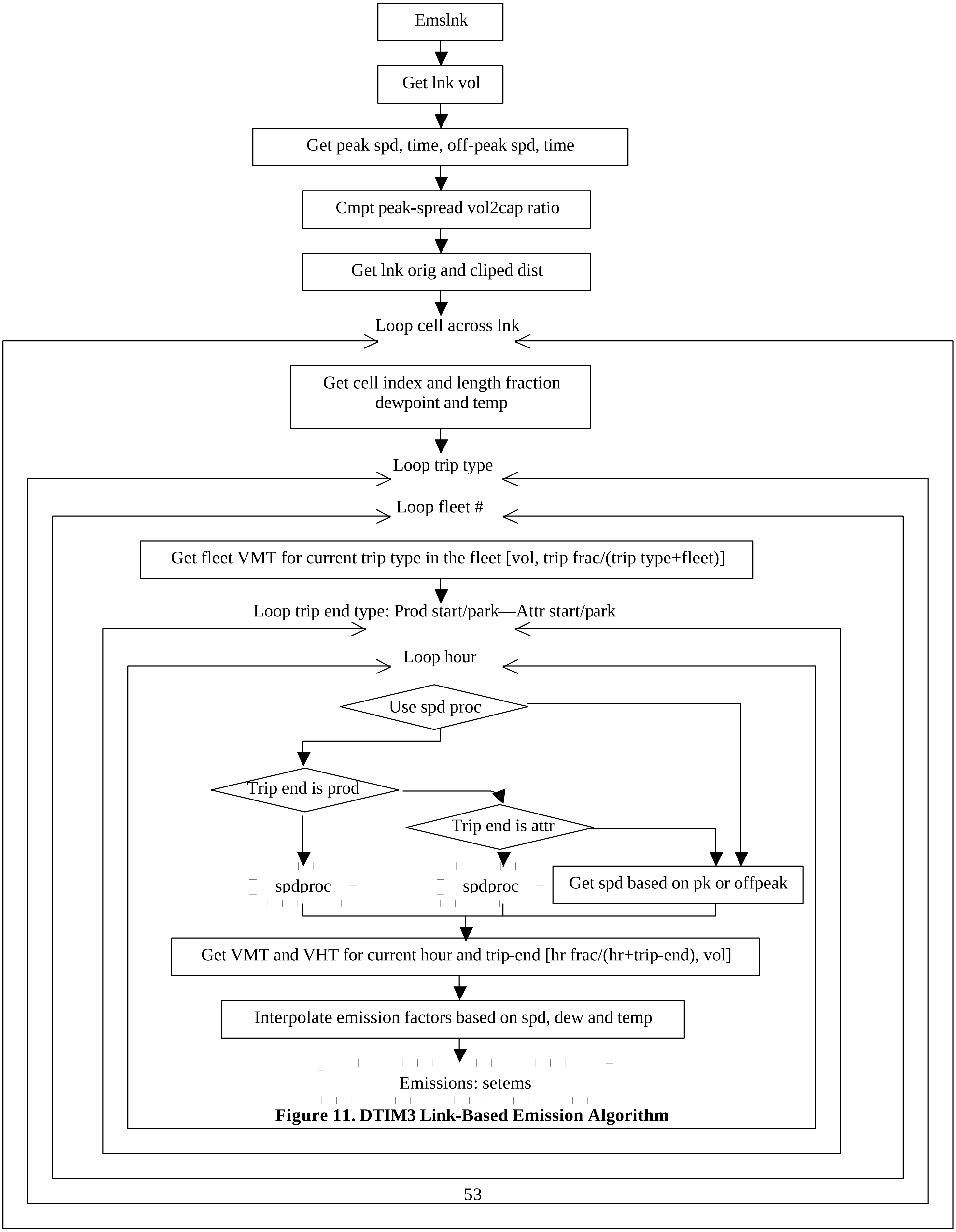

Figure 11. DTIM3 Link-Based Emission Algorithm

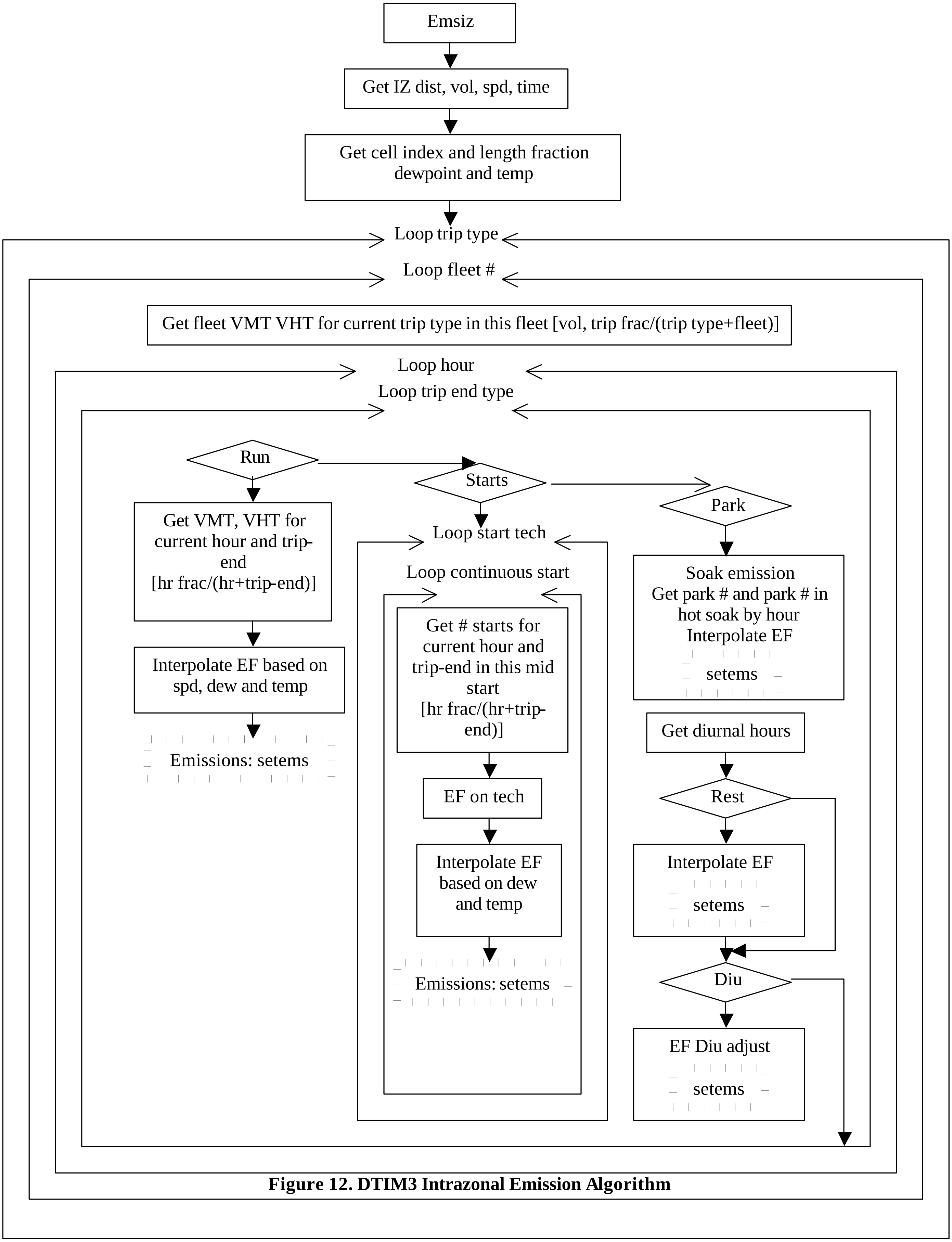

Figure 12. DTIM3 Intrazonal Emission Algorithm

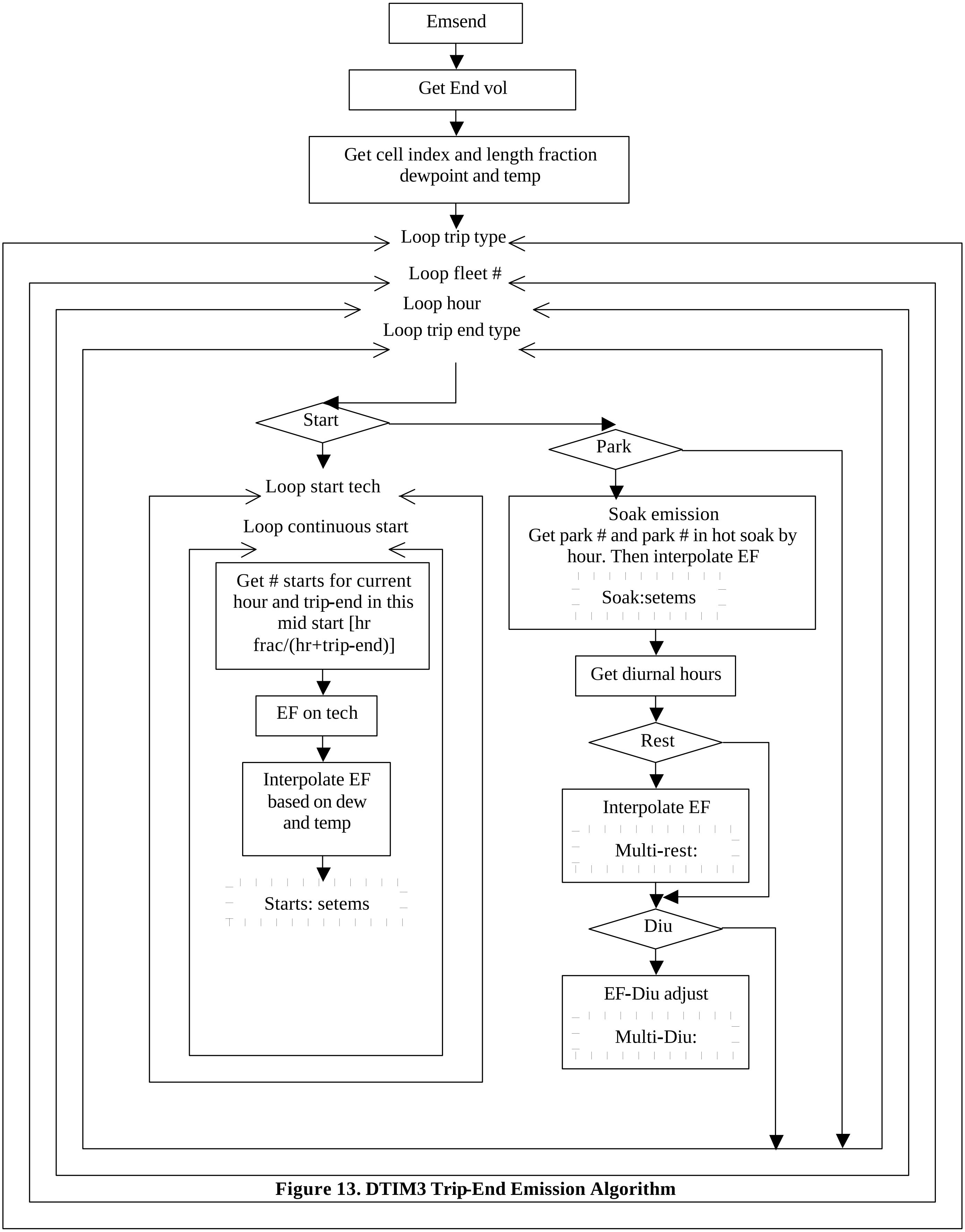

Figure 13. DTIM3 Trip-End Emission Algorithm

3.2.3 Discussion of the DTIM3 Methodology

DTIM3 was originally developed to prepare gridded emissions input for the airshed models. Because it has a convenient connection to travel demand models, DTIM3 is often used to develop emissions inventory for conformity. Theoretically, DTIM3 and BURDEN7G should generate comparable emission estimates when aggregated to the same level, such as county emission totals. However, large gaps between their estimates are always found. One fundamental reason for this mismatch is that the link-based transportation data from the travel demand models don't match trip-based emissions rates from EMFAC7G when calculating link-based emissions in DTIM3. DTIM3 ignores this problem by using the trip-based emissions rates as a proxy for link-based rates. It is not at all clear that EMFAC7G rates are as valid for the homogeneous link speeds assumed in transportation models as they are for average trip speeds.

When calculating diurnal emissions, DTIM3 double applies temperature correction factors since EMFAC7G already adjusts partial-day/multi-day diurnal emissions rates based on temperatures. DTIM3 activity data and their usage are summarized in Table 12. Because travel demand models only predict daily, or peak period and offpeak period link volumes, DTIM3 uses the disaggregation factors from the SPS file to calculate the hourly link volumes. Because the disaggregation factors in SPS file are usually derived from travel surveys, which cannot reflect the actual on-road vehicle activities, the resulting hourly link volumes in DTIM3 are arguably of lower confidence. However, recent work by Hicks and Niemeier (2000) suggests a new method that significantly improves the reliabilities of these factors.

Although there are many problems related to DTIM3 results, its grid-based algorithm has several advantages:

- The model provides a direct interface between travel demand model results and emissions rates;
- The grid cell network can be built for any modeling region;
- The methodology can be used to calculate hourly emissions;
- The regional emissions are calculated by summarizing cell-based emissions; and
- The travel demand model predicted speeds are corrected by a post-processor.

Table 12. Activity Data and Their Usages in the DTIM3 Model

Transportation Activity data	Usage in DTIM3
Length of link	Used to compute link fraction in grid cell,
Peak speed, off-peak speed for link record	Valid if speed processor is not processed Interpolate EF based on speed
Facility type	Used in speed processor and emission summary
Hourly volume & capacity per lane	Used to calculate VHT, and speed in speed processor (volume/capacity ratio)
Peak, off peak time for link record	Used to compute VHT for running emissions
Time for intrazonal or trip-end record	Used to compute intrazonal or trip-end VHT
Speed for intrazonal or trip-end record	Used to interpolate emissions rate by speed
Volume for intrazonal or trip-end record	Used to compute intrazonal or trip-end VHT
Percent of starts and distribution by hour	Used to compute VHT for start emissions
Percent of parks and percent of parks in hot soaks by hour	Used to compute VHT for hot soak emissions
Percent of diurnal parks by hour	Used to compute VHT for resting loss or diurnal emissions
Area type of link	For speed processor
Number of lanes, control type of link	For speed processor
Signal spacing, green/cycle on link	For speed processor
Arrival type for link	For speed processor

3.3 Conclusion of Evaluation

BURDEN7G and DTIM3 are the main vehicle emissions inventory models used in California. Table 13 summarizes their drawbacks and contributions.

Table 13. Drawbacks and Contributions of BURDEN7G and DTIM3 Methodology

	Drawbacks	Contributions
BURDEN7G	No direct connection to travel demand models	Computation efficiency
	Macroscopic estimates, not appropriate for small network	Correct interface between transportation and emissions rates
	Incapability of developing gridded emissions	Emission formulation
DTIM3	Inappropriate interface between transportation data and emissions rates	Direct connection to travel demand models
	Default disaggregation factors difficult to update	Capability of developing both regional inventory and gridded emissions
	Inappropriate diurnal/resting loss emissions formulas	Hourly emission estimates
		Speed post-processor

Based on the analyses in this chapter, problems with BURDEN7G and DTIM3 can be generally classified as the method limitations, which occur when matching the transportation data to emissions rates in the interface models. The BURDEN7G's macroscopic emission algorithm cannot compute microscopic gridded emissions, and the DTIM interface between the link-based transportation data and trip-based emissions rates results in inaccurate running exhaust emission estimates.

Chapter 4 will propose a new interface methodology, based on the understanding of these two methods, to resolve the method limitations. The proposed methodology will incorporate the BURDEN7G and DTIM3 advantages into the new inventory model. Among other sound methodologies that will be incorporated into the new interface model are: BURDEN7G emission formulas, DTIM3 speed post processor, and DTIM3 intrazonal emission estimates.

Before discussing the new model development in the next chapter, the following points summarize the major features that are highly desired in the new interface model. These features are summarized based on discussions in the previous chapters:

- <u>A dual-purpose model</u>: The new model has to enable users to produce gridded emissions for air quality models and countywide emission totals to feed into the SIPs. This will significantly improve the efficiency of the transportation conformity processes.
- <u>Accurate emission methodology</u>: The interface between the transportation data and emissions rates must be at the same level. This will improve the accuracy of emission inventory predictions.
- <u>Detailed emissions rates</u>: Currently, improved emissions rates to address facility differences are desired for the new model. The model should also have the optional capability to work with modal emissions rates.

CHAPTER 4. MODEL DESIGN

Based on discussions in Chapters 2 and 3, this chapter presents the design of the new transportation and emission interface model. The core purpose of the new model is to combine travel activity input from a transportation model and emissions rates input from an emissions rates model to develop emissions inventory estimates. The new model calculates the hourly mobile emissions at grid cell level, from which both gridded emissions inventory and regional emissions inventory can be easily developed. Compared to BURDEN7G/EMFAC2000, this methodology of linking two types of emissions inventories allows spatial compatibility and gives users the direct interface with transportation planning model. Compared to DTIM3, the new model uses a similar cell-based emissions computation idea, but improves the emissions estimates by incorporating fleet data to enable the EMFAC2000 evaporative emission algorithms to be used.

In the following sections, we discuss each of the five major areas associated with the model development:

- Grid mesh construction methodology,
- Emissions rates input,
- Transportation activity data input,
- The methodologies to produce emissions inventory estimates, and
- Model evaluation.

4.1 Grid Mesh Construction

To compute the gridded emissions inventory, a grid mesh of covering the modeling domain has to be constructed first. In the new model, the mesh construction methodology serves two functions:

- Create grid mesh, and
- Allocate link/trip-end/intrazonal activity data to cells.

The model uses a new method to create the grid mesh whereby the user defines some basic network information: the grid cell width and length are determined by the air quality model (i.e., Urban Airshed Model); the number of cells and the transportation network coordinates of any two points and their associated UTM coordinates are defined by users. Given these data, the new model knows the coordinates of each grid point in the cell mesh covering the entire modeling region.

To grid link based activity data, the portion of each link falling within a grid cell is calculated by finding the intersections of the link and the grid lines. The new model computes the link slope based on the coordinates of its beginning node and ending node, which are usually reported by the travel demand model for every link. The intersection of the link and each grid cell boundary is calculated by comparing the link slope to the slopes of dashed lines (the lines between the link beginning point in each grid and its upper-right grid corner in Figure 14). In Case 1, if the link slope is less than the dashed line slope in the intersection A, the X coordinate of “A” equals to the grid boundary’s X coordinate “X_1”, and the Y coordinate of “A” can be calculated based on “X_1”and the link slope. Otherwise, e.g. in the intersection “B”, the grid boundary’s Y coordinate “Y_1” becomes the Y coordinate of “B”, and the X coordinate of “B” can be calculated by “Y_1” and the link slope. The calculation of Case 2 is reverse from Case 1. We use the grid boundary’s X coordinate and the link slope to calculate the intersection’s Y coordinate if the link slope is less than the dashed line slope, and vice versa. When the coordinates of both intersections are known, the gridded link length within the cell, which will be used to calculate cell-based link VMT, can be easily calculated. The travel movements in any direction can be classified into these two cases by switching the link beginning and ending node coordinates.

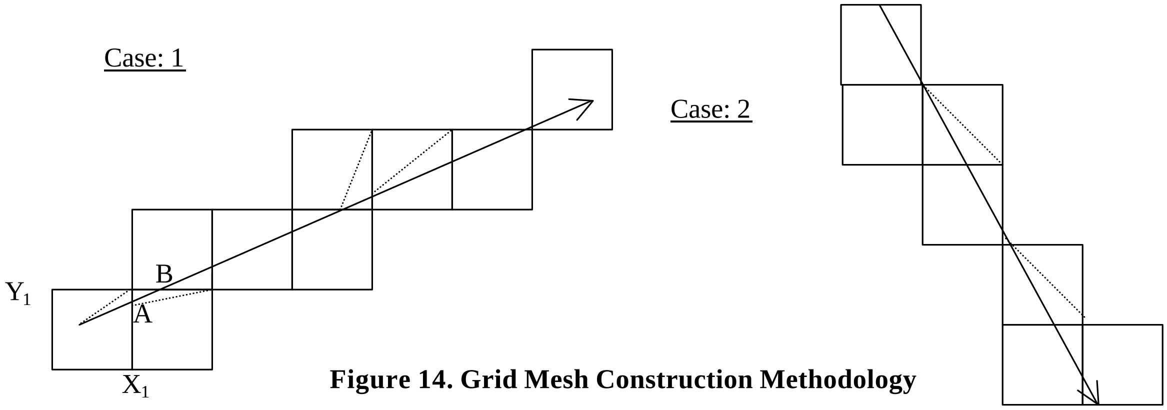

Figure 14. Grid Mesh Construction Methodology

The travel demand model uses a single TAZ centroid point to report the TAZ trip-end and intrazonal activities. When dealing with this type of zonal activity data, the new model simply allocates centroids to the correspondent grid cells. In this way, both link and zonal emissions can be computed at a grid cell. In Section 4.4.4, we discuss a new methodology using spline function interpolation to redistribute trip end and Intrazonal emissions assigned to the zone centroid to all the grid cells inside of the TAZ. These new methodologies offer advantages over the existing models.

4.2 Emissions Rates Input

EMFAC emissions rates are specific to each bin of background environment data (speed, temperature, relative humidity, or pre-start soak time). Previous in BURDEN7G, real world environment data were aggregated to bins in order to match bin-based emissions rates. For instance, the emissions rates of speed bin 35mph are used to represent all the emissions rates from speeds 30mph to 35mph. As a result, the emissions difference from the traffic improvements (traffic speed is improved from 31mph to 35mph) cannot be estimated by BURDEN7G. The new model solves this insensitivity problem by allowing users to use three types of emissions rates:

- Interpolated speed-specific EMFAC2000 emissions rates (the latest version of MVEI)
- Functional speed correction factors (SCF), from EMFAC2000, based running exhaust emissions rates, or
- CAMP facility-based running exhaust emissions rates.

To reflect the real world traffic conditions and the resulting emissions, EMFAC2000 emissions rates (i.e., speed for running exhaust emissions rates) are specifically corrected either through lineal interpolation[10] or functional representations of the speed correction factors from MVEI 2000 to produce precise speed-specific emissions rates in the new model. The CAMP facility-specific running exhaust emissions rates are being developed under the CAMP project and are expected to be available by 2003. For each of local, arterial, and freeway facilities, CAMP will generate running exhaust speed correction factors as a function of vehicle model year and vehicle class/technology. In the new integrated platform, we will use EMFAC based corrections for fuel, temperature, deterioration, and I/M, etc. with the CAMP speed correction factors to develop running exhaust emissions rates. These facility-specific running exhaust rates disaggregate travel conditions to the facility level, where speed variance is likely to be less than that represented by emission rates from trip based emission rates coded into EMFAC2000. Therefore, the CAMP facility-based running exhaust rates are more appropriate than the EMFAC2000 trip-based emissions rates for applications to the link-based interzonal transportation data.

4.2.1 Vehicle Class and Technology Definition

EMFAC2000 (ver 2.02) updated vehicle class classifications to gasoline, diesel, and electric vehicles. The previous defined non-catalyst gasoline vehicle is believed to be outdated; non-cat vehicles are represented in the gasoline technology group. The definition of vehicle class/tech group is shown in Table 14.

Table 14. Definition of Vehicle Class/Tech Group (New Model)

Light Duty Auto – Gasoline	Light Heavy Duty Truck – Gasoline
Light Duty Auto – Diesel	Light Heavy Duty Truck – Diesel
Light Duty Auto – Electric	Medium Heavy Duty Truck – Gasoline
Light Duty Truck – Gasoline	Medium Heavy Duty Truck – Diesel
Light Duty Truck – Diesel	Heavy Duty Truck – Diesel
Medium Duty Truck – Gasoline	Urban Bus – Diesel
Medium Duty Truck – Diesel	Motorcycle – Gasoline

4.2.2 Emissions Process

Table 15 shows the relationships of emission processes, pollutants, and vehicle class/tech group. Running emissions occur when vehicles are running on a roadway, and consist of two parts: running exhaust emissions, and running loss emissions for gasoline powered vehicles. CAMP running exhaust emissions rates will be provided by vehicle class/tech group and as a function of speed. Similarly, EMFAC2000 running exhaust emissions rates are provided for each vehicle class/tech group, but not by facility type. EMFAC2000 resting loss emissions rates are provided to a vehicle group by 12 temperatures (30F, 40F, 50F, 60F, 70F, 75F, 85F, 90F, 95F, 100F, 105F, and 110F).

Start emissions account for emissions during the first few minutes of vehicle operation (CARB, 1996*a*), and vary with vehicle pre-start soak time[11]. The methodology to estimate start emissions are discussed in two parts: variable start emissions and cold/hot start emissions. LDA, LDT and MDT gasoline-powered vehicle groups use the variable start methodology. The rest of vehicle types still use cold/hot starts emissions methodology. EMFAC2000 variable start emissions rates are provided for the appropriate vehicle class/tech group based on different soak bins. Pre-start soak time bins for the variable starts are defined as:

---

[10] We use simple lineal interpolation to calculate the exact emissions rates based on speed, pre-start soak time, relative humidity, and/or temperature wherever they are applicable. For example, start emissions rates are interpolated by pre-start soak time, relative humidity, and temperature.

[11] Soak time is the period after the engine has been turned off.

Pre-start Park Time Range	Pre-start Park Time Bin
Less than 2.5 min	1 minute
2.5 min to 7.5 min	5 minutes
7.5 min to 12.5 min	10 minutes
12.5 min to 27.5 min	20 minutes
27.5 min to 47.5 min	40 minutes
47.5 min to 72.5 min	60 minutes
72.5 min to 107.5 min	90 minutes
107.5 min to 137.5 min	120 minutes
137.5 min to 227.5 min	180 minutes
227.5 min to 373.5 min	300 minutes
373.5 min to 587.5 min	480 minutes
…	… Up to 1440 minutes

Park evaporative emissions include hot soak emissions, diurnal emissions, and resting loss emissions. Both diurnal and resting loss emissions are modeled as having two components: partial-day emissions and multi-day emissions. EMFAC2000 park evaporative emissions rates are used for each vehicle class/tech group.

Because all the emissions rates are given by vehicle class/tech groups, transportation data must be aggregated/disaggregated to the matching the vehicle groups. The next section discusses the processing of transportation data by time period.

Table 15. Cross-Reference Chart for Vehicle-Tech Types by Emission Process and Pollutant

Emitting Process	Light Duty Auto		Light Duty Truck		Medium Duty Truck	Heavy Duty Trucks					Urban Bus	Motor-cycle
						Light		Medium		Heavy		
	GAS	DSL	GAS	DSL	GAS	GAS	DSL	GAS	DSL	DSL	DSL	GAS
RE	A	C	A	C	A	C	C	C	C	C	A	A
CS	-	D	-	D	-	-	-	-	-	-	-	D
HS	-	D	-	D	-	-	-	-	-	-	-	D
S	B	-	B	-	B	-	-	-	-	-	-	-
DRNL	E	-	E	-	E	E	-	E	-	-	-	E
RSG	E	-	E	-	E	-	-	-	-	-	-	-
HTSK	E	-	E	-	E	E	-	E	-	-	-	E
RL	E	-	E	-	E	E	-	E	-	-	-	E
OTHER	F	F	F	F	F	F	F	F	F	F	F	F
CC	-	-	-	-	-	-	-	-	-	-	-	E
Activity Data												
POP	X	X	X	X	X	X	X	X	X	X	X	X
VMT	X	X	X	X	X	X	X	X	X	X	X	X
Starts	X	X	X	X	X	X	-	X	-	-	-	X

Source: CARB 1996*d* (without Non-Catalyst Gasoline)

A-F	Relevant combination of pollutants by vehicle-technology type and process
X	Available activity data by vehicle-technology type
-	Combination that is irrelevant, insignificant or unavailable

A TOG, CO, NO_X, CO2, PMEX
B TOG, CO, NO_X, CO2
C TOG, CO, NO_X, PMEX
D TOG, CO, NO_X
E TOG
F PMTW, PMBW, SO_2, FUEL

RE	Running Exhaust
CS	Cold Start
HS	Hot Start
S	Variable Starts
DRNL	Diurnal
RSG	Resting Loss
RL	Running Loss
PMEX	Particulate Matter Exhaust
Other	Lead, Particulate Matter (Tire and Brake Wear), SO_2, Fuel Consumption
CC	Crankcase Blowby

POP	Vehicle Population
GAS	Catalyst Gasoline
DSL	Diesel
VMT	Vehicle Miles Traveled
Starts	Vehicle Starts

4.3 Transportation Activity Data Input

Recall that travel activities in a model network are classified into three types: interzonal travel, intrazonal travel, and external travel. The widely used standard four-step travel demand models explicitly predict interzonal travel, but not intrazonal travel. External travel, not specifically modeled in the transportation models, is usually treated as part of interzonal travel. The new model thus relies on the standard four-step model to prepare all the travel activities, which are classified into three types:

- Link Activity Data (interzonal running activities)
- Trip-End Activity Data (interzonal start and park activities), and
- Intrazonal Activity Data (intrazonal running, start, and park activities).

Because these data are usually provided by multi-hour time period (e.g., peak period) and by vehicle class, not the needed one-hour time period and vehicle class/tech group, they have to be disaggregated into hourly cell-based data by vehicle class/tech group for the use of emissions inventory development.

4.3.1 Interzonal Link Running Activity

The interzonal link-based running data, representing the link running activities resulting from zone to zone travel (e.g., commute trips), are allocated into cells by the mesh construction algorithm.

The emission processes and related transportation data needed are listed in Table 16. The link node X, Y coordinates, link running volume, link facility type, link distance and speed, and link capacity (for speed processor) are standard outputs of four-step models. Vehicle fleet composition and percent of running volume by hour are user inputs. The University of California at Davis has developed a default set of allocation factors for the percent of running volumes by hour based on observed counter data (Lin and Niemeier 1998, Niemeier *et al.*, 1999). Percent of VMT by vehicle class/tech group default to those provided by EMFAC2000.

Table 16. Emission Process and Interzonal Link Data

Emission Process	Transportation Data (Source = User, TDM or MVEI)
Interzonal Running Exhaust/Loss Emission	• Link node X, Y coordinates, link facility type, link volume (TDM), • Link distance, speed, link capacity (TDM, for speed processor), • Vehicle fleet composition (User), volume percent by hour (MVEI/User), • Percent of VMT by vehicle class/tech group (MVEI)

The link volumes are divided into hourly volumes based on percent of running volume by hour, and then are combined with the cell-based link length, the fleet composition, and percent of volume by vehicle class/tech group to develop the hourly cell-based VMT for each vehicle class/tech group. Users will have an option to use the speed post-processor (the same methodology of the DTIM3 speed processor) to recalculate link speed to replace the four-step model estimated link speed.

4.3.2 Interzonal Starts and Parks Activity

The trip-end data, reported at the TAZ centroids, represent the interzonal starts and parks activities resulting from zone to zone travel. The mesh construction algorithm maps every trip-end record to a single cell where the TAZ centroid is located. The trip-end activities data from the four-step models include: TAZ ID, number of trips by production (starts) and attraction (parks) for each multi-hour time period. Additional activity data needed include zonal vehicle population, percent of start and park by hour, pre-start soak time distribution for each hour, percent of hot soak park by hour. These zonal data, together with EMFAC2000 start and population percentages by vehicle class/tech group and fleet composition, are used to estimate the hourly interzonal starts, hot soaks, multi-day diurnal parks, and multi-day resting loss parks. These data and their associated emission processes are summarized in Table 17. Users can choose to use the EMFAC2000 default percentages in the new model.

Table 17. Emission Process and Interzonal Trip-End Data

Emission Process	Transportation Data (Source = User, TDM or MVEI)
Start Emission	• Starts per period (TDM), • Starts percent by hour, start by soak time distribution by hour (MVEI), • Percent of start by vehicle class/tech group, fleet composition (MVEI)
Hot Soak Emission	• Parks per period (TDM), • Parks percent of by hour, percent of parks resulting in hot soak by hour (MVEI/User), • Parks Percent by vehicle class/tech (MVEI), fleet composition (User)
Multi Day Diurnal and Resting Loss Emission	• Zonal vehicle population, percent of population by vehicle class/tech (MVEI), • Fleet composition (User)

4.3.3 Intrazonal Activity

Similar to trip-end data, the intrazonal activities, which remain totally within the originating zones, are reported at TAZ centroids by the four-step models. The data include: TAZ ID, intrazonal travel volume, mean intrazonal travel time, and mean intrazonal travel distance. These data for each TAZ are also mapped into a single cell wherever the TAZ centroid is located. All the transportation data input and their associated emission processes are listed in Table 18. The new model provides the default EMFAC2000 values to all the percentage inputs when users don't want to create their own inputs. These data are used to disaggregate the multi-hour intrazonal data into hourly data. The fleet composition, and percents of VMT and start by vehicle class/tech group from EMFAC2000 are used to further divide intrazonal volumes into various vehicle class/tech groups. After these two disaggregations, the hourly intrazonal running, starts, hot soaks, partial-day diurnal parks, and partial-day resting loss parks by vehicle class/tech groups are derived.

Table 18. Emission Process and Intrazonal Transportation Data

Emission Process	Transportation Data (Source = User, TDM or MVEI)
Running Exhaust/ Loss Emission	• Intrazonal volume, mean intrazonal travel time and distance (TDM), • Percent of running volume by hour (MVEI), • VMT Percent by vehicle class/tech (MVEI), fleet composition (User)
Start Emission	• Starts/parks per period (TDM), • Start by soak time distribution by hour (MVEI), • Start Percent by vehicle class/tech (MVEI), fleet composition (User)
Hot Soak Emission	• Starts/parks per period (TDM), • Percent of parks by hour, percent of parks resulting in hot soak by hour (MVEI/User), • Parks percent by vehicle class/tech (MVEI), fleet composition (User)
Partial Day Diurnal and Resting Loss Emission	• Starts/parks per period (TDM), • Percent of parks by hour, percent of diurnal parks in each hour that result in diurnals / resting losses (MVEI/User), • Parks percent by vehicle class/tech (MVEI), fleet composition (User)

4.4 Emissions Inventory Development

Generally, emissions rates are specified by the combinations of vehicle class/tech group, calendar year, season, and I/M program. For any given modeling area, the emissions rates model (e.g., EMFAC2000) produces the correct pool of emissions rates (either with or without I/M, and either the summer or winter season) based on the specification of modeling area. Then, more detailed emissions rates are selected specifically in each grid cell based on vehicle class/tech group, facility type if applicable, and background environment information.

The new model divides a day into 24 one-hour time periods. For each hour, the transportation and emissions rates interfaces are divided into three types: the first for interzonal link activities, the second for interzonal trip-end starts/parks activities, and the last for the intrazonal running/starts/parks activities (Figure 15). Each of these three types of interfaces is introduced below. The summations of emissions from all the interfaces become the regional emissions inventory. The gridded emissions inventory is introduced in Section 4.4.4.

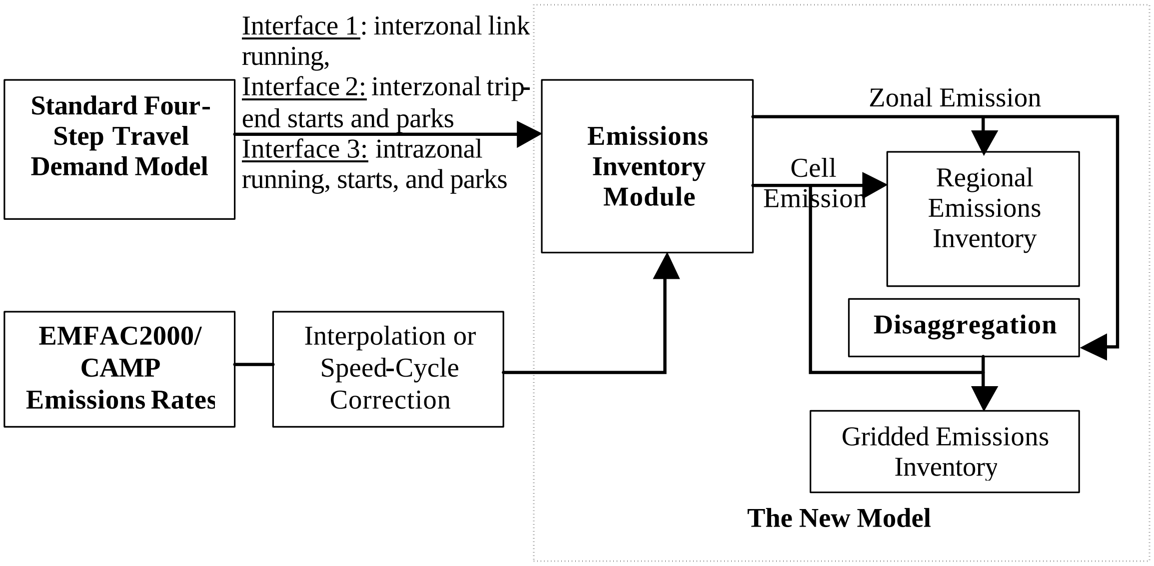

Figure 15. The Modeling Method of the New Model

4.4.1 Interzonal Running Emissions and Fuel Consumption (Interface 1)

The emissions inventory module estimates interzonal running emissions and fuel consumption based on a combination of DTIM3 and EMFAC2000 methodologies (e.g., the default EMFAC2000 percentages and the new ratios to break down running volumes by hour based on the observed counter data), and use the CAMP facility-specific running exhaust emissions rates when they are available. The cell-contained link hourly VMT derived from Section 4.3.1 is multiplied by the appropriate running exhaust emissions rates to calculate cell-based interzonal running exhaust emissions (Equation 18). The running loss emissions are calculated using Equation 18, but based on the EMFAC2000 running loss emissions rates.

$$RE = dist \times cell \times vol \times fleet \times frac \times stable \times EF \qquad \text{------- Equation 18}$$

where

RE = Running exhaust emissions

dist = Interzonal link distance

cell = Cell-portion link fraction

vol = Interzonal link volume

fleet = Vehicle class fraction in the fleet
frac = Percent of VMT by vehicle class/tech group from EMFAC2000
stable = Percent of running volume by hour
EF = Interpolated/functional SCF-based EMFAC2000 or CAMP running exhaust emissions rates

Because CO_2 emissions for LDA and MDT gasoline vehicles are already available from the above calculations, the fuel consumed for these vehicles can be estimated by using the BURDEN7G carbon balance methodology (Equation 19). All the other vehicle classes use the Corporate Average Fuel Economy (CAFE) standards and vehicle activity to calculate fuel consumption (same equation as Equation 18, but with different units). SO_x emissions are computed based on fuel consumption (Equation 20).

$$FC = \frac{(.429 \times CO + .273 \times CO_2 + .866 \times TOG) \times 2000 lb / ton}{.841 \times (6.34 lb / gal)}$$ ------- Equation 19

where

FC = Fuel consumption
CO = Summation of running exhaust and start CO emissions
CO_2 = Summation of running exhaust and start CO_2 emissions
TOG = (Running exhaust + start + running loss) emissions

$$SOx = FC \times SF \times FD \times RSOx$$ --------- Equation 20

where

SO_x = Oxides of sulfur emissions
FC = Fuel consumption
SF = Conversion factor from S to SO_2
FD = Fuel density; 297 lb/bbl for diesel, 265.5 lb/bbl for gas
RSO_x = Sulfur (ppm-by-weight/gal of fuel)

4.4.2 Interzonal Start/Park Emissions (Interface 2)

The interzonal emission processes are:

- Interzonal start emissions, and

- Interzonal hot soak, multi-day diurnal and multi-day resting loss evaporative emissions.

In this interface, fleet population data are used for consistency with EMFAC2000, overcoming one of the historic shortfalls of DTIM, which has always tried to estimate diurnals without the population data.

Interzonal Start Emissions: In each hour, interzonal number of starts is multiplied by the percent of starts by vehicle class/tech group, percent of starts by hour, percent of starts by soak time bin, and variable start emissions rates to compute the interzonal variable start emissions (Equation 21). These are computed for each TAZ by one-hour period.

$$VS = \sum_{n=1}^{12} (vol \times fleet \times frac \times starts \times midstt \times EF) \qquad \text{------- Equation 21}$$

where

VS = Interzonal variable start emissions
vol = Interzonal number of starts
fleet = Vehicle class fraction in the fleet
frac = Percent of starts by vehicle class/tech group from EMFAC2000
starts = Percent of starts in each hour
midstt = Percent of starts by soak time in each hour
EF = Start emissions rates from EMFAC2000
n = Soak time bins (1 to 12 for variable starts)

Interzonal hot soak emissions: Interzonal number of parks is multiplied by the percent of starts (parks) by vehicle class/tech group, percent of parks by hour, percent of parks resulting in hot soaks, and hot soak emissions rates to compute hot soak emissions (Equation 22). It is done for each TAZ by one-hour period.

$$HTSK = vol \times fleet \times frac \times parks \times hotprk \times EF \qquad \text{------- Equation 22}$$

where

HTSK = Hot soak emission
vol = Interzonal number of parks
fleet = Vehicle class fraction in the fleet
frac = Percent of starts by vehicle class/tech group from EMFAC2000
parks = Percent of parks in each hour

hotprk = Percent of parks in hot soaks in each hour
EF = Hot soak emissions rates from EMFAC2000

Interzonal multi-day diurnal and resting loss emissions: Based on BURDEN7G methodology, every vehicle is assumed to have both multi-day diurnal emissions and multi-day resting loss emissions. Multi-day diurnal emissions are computed for all the appropriate vehicle groups in each TAZ using Equation 23 by one-hour period. Multi-day resting loss emissions are calculated in the same way as Equation 23.

$$MDIU = \frac{pop \times fleet \times frac \times EF}{24} \qquad \text{-------- Equation 23}$$

where

MDIU = Multi-day diurnal emissions
pop = Zonal vehicle population
fleet = Vehicle class fraction in the fleet
frac = Percent of population by vehicle class/tech group from EMFAC2000
EF = Multi-day diurnal emissions rates from EMFAC2000

4.4.3 Intrazonal Running/Starts/Parks Emissions (Interface 3)

The intrazonal emission algorithms follow the DTIM3 intrazonal methodologies and BURDEN7G formulas. The emissions processes include:

- Intrazonal running emissions and fuel consumption,
- Intrazonal start emissions, and
- Intrazonal hot soak, partial-day diurnal, and partial-day resting loss evaporative emissions.

CAMP running exhaust emissions rates are not used in calculating intrazonal emissions because a travel demand model reports intrazonal data on a trip basis rather than a link basis.

Intrazonal running emissions and fuel consumption: Using Equation 24, the emission module calculates intrazonal running exhaust/loss emissions as the products of intrazonal mean distance, intrazonal volume, vehicle class fraction, percent of VMT by vehicle class/tech group, running percent by hour, and EMFAC2000 running emissions rates. Fuel consumption and SO_x emissions use Equation 19-20. These calculations are computed for each TAZ by hour.

$$RE = dist \times vol \times fleet \times frac \times stable \times EF \qquad \text{------- Equation 24}$$

where

RE = Intrazonal running exhaust/loss emissions
dist = Intrazonal mean distance
vol = Intrazonal volume
fleet = Vehicle class fraction in the fleet
frac = Percent of VMT by vehicle class/tech group from EMFAC2000
stable = Percent of running volume by hour
EF = EMFAC2000 running exhaust/loss emissions rates

Intrazonal start emissions: The methodology to compute intrazonal start emissions is the same as that in interzonal start emissions (Equation 21), except that interzonal number of starts is replaced by the intrazonal volume.

Intrazonal hot soak emissions: The methodology is the same as that in interzonal hot soak emissions (Equation 22), except that interzonal number of parks is replaced by the intrazonal volume.

Intrazonal partial-day diurnal emissions: If temperature increases in the current hour, the intrazonal volume is multiplied by vehicle class fraction, percent of starts (parks) by vehicle class/tech group, percent of diurnal parks, and partial-day diurnal emission rates to compute partial-day diurnal emissions (Equation 25). This is calculated for each TAZ by one-hour period.

$$PDIU = vol \times fleet \times frac \times prk \times diuprk \times EF \qquad \text{------- Equation 25}$$

where

PDIU = Partial-day diurnal emissions
vol = Intrazonal volume
fleet = Vehicle class fraction in the fleet
frac = Percent of starts by vehicle class/tech group from EMFAC2000
prk = Percent of park in each hour
diuprk = Percent of parks in diurnal in each hour

EF = Partial-day diurnal emission rates

Intrazonal partial-day resting loss emissions: If temperature decreases or stay constant in the current hour, partial-day resting loss emissions occur. They are calculated in the same way as partial-day diurnal emissions (Equation 25).

4.4.4 Disaggregation of Interzonal Trip-End and Intrazonal Emissions into Grid Cells

Since TAZs may usually encompass any number of grid cells within their boundaries, and both interzonal trip-end and intrazonal data are reported on a TAZ basis from the travel demand model, which result in a TAZ level emissions at a centroid cell, we have to have a method for allocating TAZ level emissions into grid cells. To achieve this purpose, the disaggregation module distributes the TAZ level emissions from a centroid cell to the network based on a derived spline interpolation function using the areas of TAZs and TAZ volumes. These cell emissions are then summed with cell-based interzonal running emissions for the gridded emissions inventory.

As the emissions standards are becoming stricter, running exhaust emissions account for a smaller percentage of the mobile emissions. As a result, the start and park emissions (including diurnals in our discussion), which are on a TAZ level, are becoming increasingly more significant in air quality modeling. Therefore, the existing methodology of allocating TAZ level emissions to a single centroid cell may be too simplistic. This new disaggregation methodology to develop the gridded emissions inventory will improve the accuracy of mobile-source input to the air quality model.

4.5 Model Evaluation

Since MVEI7G/EMFAC2000 is the current California emissions inventory model, the regional emissions inventory from the new model must be compared to the emissions inventory developed by MVEI7G/EMFAC2000 as a part of model evaluation. The Sacramento metropolitan areas will be used as the case study area, with MVEI7G/EMFAC2000 inventories serving as the basis for comparison. The inventories will be computed using the new model and compared to the MVEI7G/EMFAC2000 inventories by emission processes (running, starts, and parks emissions) and emission species (TOG, CO, NOx, CO_2, fuel, PM, and SO_2). These comparison results will help to determine the model replicability with the approved model, MVEI7G/EMFAC2000.

Sensitivity of the new model to the new inputs and cell-based algorithms will also be evaluated. The sensitivity analyses will include the effects on inventories when cell size is changed, the effects of using EMFAC2000 running exhaust emissions rates instead of CAMP running exhaust emissions rates, and the effects of using non EMFAC2000 default values.

For the cell-size sensitivity analyses, the regional emissions inventories using the cell size of the current airshed model (usually 4km) will be set as the base case. The inventories using the decreased/increased cell size (1km, 7km, and 10km) will be compared to the base inventories. The sensitivity of computation time to the cell size will also be evaluated. To study the model sensitivity to the CAMP emissions rates, the interzonal running exhaust emissions inventories using the EMFAC2000 running exhaust emissions rates will be compared to the inventories using CAMP rates. To study the model sensitivity to non EMFAC2000 default values, the local inputs and several scenarios will be used to run the model. The sensitivity analyses will help users to improve modeling accuracy by carefully preparing the emissions-sensitive inputs in the modeling process.

CHAPTER 5. DISCUSSION AND TIMELINE

This chapter discusses the advantages and disadvantages of the new transportation and emission interface model. The timeline for the study is presented at the end of the chapter.

5.1 Advantages and Disadvantages of the Proposed Methodology

5.1.1 Advantages and Contributions

The speed-cycle correction methodology, adjusting running exhaust emissions rates to the "real" traveling speed based on the speed correction curves, is more theoretically sound than the simple interpolation method when estimating emissions rates. The CAMP methodology, by applying link-based transportation data to link-based CAMP emissions rates at cell level, makes the dual-purpose concept (regional emissions inventory and gridded emissions inventory) possible. The CAMP methodology will also overcome a previous methodological drawback (the trip-based vs. link-based problem) encountered when calculating link or gridded emissions. Theoretically, the gap between the regional emissions inventory and gridded emissions will be rectified in the new interface model. These new interpolated/functional SCF-based or CAMP facility-specific running exhaust emissions rates should improve the accuracy of emission estimates. At the same time, the proposed program balances computational efficiency with modeling resolution.

Data and procedures from MVEI 2000 are being incorporated into the new model to provide default population and distribution data to describe the necessary default values to replicate the evaporative emissions calculations that have traditionally challenged DTIM. Model year specific population data by vehicle class and technology are calculated using the MVEI methodology, starting with the 1997 fleet and forecasting / backcasting as appropriate. This data allows the new model to apply speed correction factors at the link level. By incorporating the SCF's into the model we are illuminating the rounding and interpolation errors as well as providing a framework that allows the implementation of the CAMP SCFs when they become available.

Based on the BURDEN7G methodology, every vehicle is assumed to experience both multi-day diurnal and resting loss emissions during the overnight parks. However, DTIM3 only calculates one of them, and uses the number of trips instead of the vehicle population as in BURDEN7G. The new model will produce better multi-day diurnal and resting loss emissions by re-formulating the equations based on the BURDEN7G method.

The disaggregation of zonal emissions into grid cells will also improve the gridded emissions inventory -- DTIM3 allocates zonal emissions to a single grid cell (TAZ centroid) instead of distributing to multiple cells[12].

Because of the improvements of the emissions algorithms and emissions rates, the new model can be better applied to evaluate emission impacts of various transportation projects ranging from regional level effects to project level effects. This will further the integration of transportation planning and air quality planning. Thus, the new model is expected to be a powerful tool for conformity analyses. The spatial and temporal distribution of vehicle gridded emissions will help to enhance air quality modeling and attainment planning.

5.1.2 Disadvantages

Multi-hour time period transportation activity data must be divided into hourly data for the emissions estimates. The breakdown ratios are usually difficult to update, and only approximate the true distributions. The new model will have a connection to DYNASMART, the dynamic traffic assignment and simulation model developed by the University of Texas-Austin. Using the DYNASMART interface, no additional data from outside of the model will be required. The emissions inventories estimated by the DYNASMART interface are expected to be more accurate since DYNASMART is capable of providing detailed spatial and temporal transportation activity data to the emissions inventory model.

Finally, the emissions rates used in the new model are speed-based. When modal emissions rates are available, future efforts will be needed to extend the interface methodology.

5.2 Timeline

The cooperation of Caltrans and UC-Davis is highly important to this study.

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[12] The PIOS file used to distribute zonal emissions to grid cells in DTIM3 is rarely available in the regional planning agencies (Systems Application International, 1998*a*).

The Sacramento Area Council of Governments (SACOG) will provide detailed Sacramento (SACMET) network data, including link X Y coordinates, facility type, and signal ramp control information.

The new model will be written in FORTRAN90. This procedure is the main work in the project.

It’s expected that a test version of the new model can come out by the end of September 2001.

This schedule is subject to change.

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