LINKING TRAVEL DEMAND MANAGEMENT AND EMISSION ESTIMATION TOOLS

BY

PRASHANTH K. RUDRANGI

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APPROVED:

Dr. R. Sivanandan
(Chairman)

Dr. Antonio A. Trani

Mr. Jerry D. Everett

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BY

Prashanth K. Rudrangi

Dr. R. Sivanandan, Chairman

Civil Engineering Department

(ABSTRACT)

Passage of Clean Air Act Amendments of 1990 have placed greater responsibility on transportation planners, requiring greater integration of transportation and air quality planning processes. Inclusion of Travel Demand Management (TDM) measures into a State Implementation Plan (SIP) or a Transportation Improvement Program (TIP) requires the evaluation of these measures for emission impacts. Traditional method of analysis of a TDM measure using TDM software is labor intensive and time consuming. This process involves the execution of the four step travel demand forecasting models for each emission analysis. This could delay the process of approving a transportation program to be included in the State Implementation Plan.

To simplify the process of emission impact analysis of TDMs using TDM software, a link between TDM software and MOBILE5a was developed. In developing the linkage, three parameters were considered crucial. These three parameters were the VMT mix, speed, and operating mode mix. It was determined that the changes in the

values of these parameters would have substantial impact on emission factors. Methodologies were formulated to predict the changes in the values of these parameters due to the implementation of TDM measures. To predict the changes in the VMT mix factors, vehicle composition rates were developed by analyzing the 1990 National Personal Transportation Survey (NPTS). Changes in speed and operating mode mix were estimated using the methodologies developed by Sierra Research, Inc.

A software model called TDMLinK was developed to link the TDM software and MOBILE5a. The three methodologies developed to predict the changes in the value of parameters were incorporated into this software. TDMLinK reports the percent reductions of emissions for each TDM scenario modeled and for each pollutant. This software extends the ability of TDM software to do screening analysis of TDM strategies.

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1. INTRODUCTION

1.1 BACKGROUND

There are many new transportation related provisions in the Clean Air Act Amendments (CAAA) of 1990. The provisions of the CAAAs, in general, require greater integration of transportation and air quality planning processes. The major impact of the CAAAs is observed on the transportation planning and project development process in areas not meeting the National Ambient Air Quality Standards for ozone and carbon monoxide. The provisions provide for renewed emphasis on controlling the growth in Vehicle Miles Traveled (VMT). The provisions also provide for expanded use of highway sanctions. A further requirement is for the development of State Implementation Plans (SIPs) by states which must include the following: current emissions inventory, air quality conditions, and the identification of measures to be implemented that will enable the area achieve the national ambient air quality standards by a designated date.

Emission inventories are developed for all significant mobile, stationary and area sources of pollutants, as part of SIP. These inventories are prepared for the base year and are used as a baseline condition against which the emissions from transportation plans and programs will be compared. Mobile source inventories include emissions from all transportation sources, both on-road and off-road. In order to reduce the on-road mobile emissions, some areas include Transportation Control Measures (TCM) in their SIP.

Title I of the CAAA outlines the requirements related to the conformity of transportation plans, programs and projects. Specifically, air pollutant emissions occurring as a result of changes to an area's transportation network cannot [3]:

1. cause or contribute to new violations of the national ambient air quality standards,
2. increase the frequency or severity of violations, or
3. delay the attainment of the standards or any required interim emission reductions

Policy makers need a good understanding of the expected impacts of TCMs before they can make effective decisions about including the measures in SIPs, Transportation Plans and TIPs. This necessitates a thorough analysis of the Transportation Control Measures to estimate their impact on trips, VMT and emissions.

Transportation Control Measure, as defined by California Clean Air Act, is:

"Any strategy to reduce vehicle trips, vehicle miles traveled, vehicle idling, or traffic congestion for the purpose of reducing motor vehicle emissions".

The official definition of a TCM as contained in the conformity regulations of CAAAs is:

"Any measure that is specifically identified and committed to in the applicable implementation plan that is either one of the types listed in §108(f) of the Clean Air Act, or any other measure for the purpose of reducing emission or concentrations of air pollutants from transportation sources by reducing vehicle use or changing traffic flow or congestion conditions".

Table 1-1 lists the 16 broad TCM categories included in the Clean Air Act Amendments. Transportation Control Measures can be grouped as Travel Demand Management (TDM) and Transportation System Management (TSM) measures. Transportation System Management measures do not contribute to any reduction of vehicle trips, but attempt to improve the operating efficiency of the transportation system.

Table 1-1 TCMs listed in the Clean Air Act §108(f)

1	Programs for improved public transit;
2	HOV and bus lanes (construction of and conversion of existing lanes to);
3	Employer based transportation management plans, including incentives;
4	Trip-reduction ordinances;
5	Traffic flow improvement programs that reduce emissions;
6	Parking facilities for multiple occupancy vehicle programs or transit service;
7	Vehicle use restrictions in downtown or other high emission areas, especially during peak use periods;
8	Programs providing for all forms of high-occupancy and shared ride services;
9	Programs limiting portions of roads or sections of metropolitan areas to non-motorized vehicular use or pedestrian use (both temporal and spatial restrictions);
10	Bicycle use incentives in both private and public areas;
11	Idling restrictions;
12	Cold-start emission restrictions (in accordance with Title II);
13	Employer-sponsored programs to permit flexible work schedules;
14	Programs and restrictions to promote non-single occupant automobile travel as part of the transportation planning and development efforts of a locality (new shopping centers, special events and other centers of vehicle activity included);
15	Programs for new construction of and major reconstruction of paths, tracks, or areas solely for the use by pedestrian or non-motorized means of transportation when economically feasible and in the public interest; and
16	Programs to encourage the voluntary removal from use and from the marketplace of pre-1980 model year light duty vehicles and pre-1980 model light duty trucks.

This may result in fewer accelerations, decelerations, less idle time, and possibly higher travel speeds. Examples of TSM measures are left turn lanes, park and ride lots for transit, improved transit services, reversible lanes, improved traffic signal coordination and ramp metering.

Travel Demand Management measures act to reduce the demand vehicle trips and at the same time sustain or increase the movement of people. Common TDM measures include carpool, VANPOOL, HOV lanes, Telecommuting, ride share promotion, parking management and some transit measures. These TDM strategies can impact the spatial, temporal and modal distribution of trips. Spatial impact is caused by diverting traffic to under-utilized routes. Spreading the demand for travel to off-peak hours would be a temporal response. Encouraging an increase in vehicle occupancy and use of public

transit could cause a change in travel mode. Finally TDM measures could actually eliminate some trips.

1.2 Emission Reduction Estimation

Emission analyses of TDM measures are performed for several reasons. One common reason is to estimate the benefits a measure would have when it is being considered for inclusion in the SIP. Additionally, emission analyses of TDM measures are commonly performed for the development of a region's TIP. The process of estimation of vehicle emissions reductions involves two stages: estimation of travel related parameters and estimation of vehicle emissions. Travel related parameters such as VMT, number of trips and speed are estimated using travel analysis tools. An emission factor model uses the output from the travel analysis tools to estimate the emission factors for various pollutants. The emission factors are obtained in terms of g/mile. These emission factors are multiplied with VMT to obtain the total emissions for various pollutants. MOBILE5a is the predominantly used emission factor model and is mandated by Environmental Protection Agency (EPA). Section 2.2.2 explains more about MOBILE5a's inputs, outputs and calculation methodology.

1.3 Research Objectives

Some of the traditional travel analysis tools used in the estimation of the travel related parameters are sketch planning techniques or analytical tools such as TDM software of Federal Highway Administration (FHWA). These are used in association with the travel demand forecasting models. The involvement of the travel demand forecasting models makes the traditional procedure for estimating the reduction in vehicle emissions quite labor intensive. They are also cumbersome and time consuming when

several measures must be analyzed. If a transportation plan or program does not meet the conformity requirements, it would need to be amended. New TCMs may need to be incorporated into the transportation plans and programs to assist in meeting the conformity standards. This may require testing of different alternatives. This could result in delay of advancement of transportation projects. An alternative analysis method needs to be devised, which is easy to implement and is less time-and labor-intensive than current procedures.

TDM software is designed to estimate the effect of Travel Demand Management strategies on travel related parameters. The TDM software does not have any built-in ability to perform the emission analysis. It has the ability to interact with four step models and perform the evaluation of TDM strategies for a existing network using trip tables. Section 2.2.1 describes more about the TDM software.

Following are the objectives of this research:

1) To develop a direct link between the TDM software and MOBILE5a, to curtail the lengthy process of estimating reductions in vehicle emissions due to the implementation of the Travel Demand Management strategies.
2) To improve the efficiency of the process of developing TDM strategies for the development of a SIP or a TIP.
3) To enhance the usefulness and to extend the abilities of TDM software perform the emission reduction estimations due to the implementation of the TDM strategies.
4) To develop vehicle composition rates for different levels of vehicle occupancy. These vehicle composition rates are used in the estimation of the VMT mix, required to compute the composite emission factors.

1.4 Scope of the Research

A software package called TDMLinK has been developed to link the TDM software and MOBILE5a. This software is intended to be used as a guidance tool in evaluating the merits of various TDM strategies in developing a SIP or TIP. The software has been designed to provide the user with summary reductions of emissions, in the form of percentage reductions achieved for pollutant. The total emissions calculated for each pollutant varies by method used to calculate them. Thus, the actual total emissions calculated by TDMLinK may be different from the emissions calculated using travel demand forecasting models. Thus, to resolve the ambiguity about which emissions to be used, only percentage reduction in emissions is reported by TDMLinK. This software package can be used to make trial estimates of reductions, usually known as screening analysis, using various sets of TDM strategies. If the desired level of reductions is obtained for a particular set of TDM strategies, then those set of TDM strategies can be used to estimate the total emission using the traditional process of emissions estimation.

1.5 Issues Considered

Implementation of Travel Demand Management strategies result in change of values of various travel related parameters which affect the emission factors. Change in the values of three such parameters: operating mode mix, speed and VMT mix, have been considered to have significant effect on the values of emission factors. Thus, effect of change in the values of these parameters have been studied for the purpose of this project. These parameters and the significance of their value on estimating emission factors are explained below.

1.5.1 Operating Mode Mix

Emission factors are dependent on the operating mode mix of the vehicle fleet in consideration. The total VMT accumulated by each trip is split into three operating modes: cold start transient, hot start transient and hot stabilized modes. Operating mode mix is the percent of VMT in the cold start transient, hot start transient and the hot stabilized modes. The EPA had defined a cold start to be any start that occurs four hours or later following the end of the preceding trip for non-catalyst equipped vehicles, and one hour or later following the end of the preceding trip for catalyst equipped vehicles. Hot starts are those starts that occur less than four hours after the end of preceding trip for non-catalyst vehicles, and less than one hour after the end of preceding trip for catalyst equipped vehicles. Cold/Hot start conditions exist till the first 3.59 miles of a trip. The remaining portion of the trip is considered to be in stabilized operating mode. Emissions are greater when a vehicle is in a cold or hot start modes as compared to a stabilized operating mode.

During the study of TDM impacts, the reduction in the value of total VMT does not necessarily represent proportional change in the VMT accumulated by each operating mode. This is illustrated by TDM policies such as Park & Ride, which may reduce trip lengths, but the reduction in VMT is not of proportional nature, as the portion of the cold start mode in VMT is not reduced significantly. This would result in change of operating mode mix value. Higher value of the cold start portion of VMT results in a higher CO and HC emissions. Thus, determination of change in operating mode mix value is essential in the estimation of emission reductions. An alternative method developed by Sierra Research has been used to calculate the emission factors taking into consideration the change in the operating mode mix.

1.5.2 Speed

MOBILE5a emission factors are sensitive to the travel speeds. MOBILE5a requires the average area wide speed to be specified. The emission factors have a non-linear relationship with the value of speed, with emission factors increasing as speed declines below 19.6 mph. However the HC and CO emission factors follow a declining path when the speed increases in the range of 19.6 mph to 48 mph. However, behavior of NOx is different from those of other two pollutants. To evaluate the emission factors accurately, change in the value of speed has to be estimated. The change of average speeds due to the TDM action cannot be determined from the TDM software directly. To accomplish this, elasticity of speed with respect to volume is used to calculate the change in the value of speed due to the implementation of the Travel Demand Management policies.

1.5.3 VMT Mix

MOBILE5a calculates emission factors for eight different vehicle classes, classified on the basis of their functionality, weight and fuel usage. These eight different vehicle classes are shown in Table 1-2.

VMT mix is expressed as the percent of total VMT (expressed in decimals) accumulated by each vehicle class. For example 0.782, 0.083, 0.047, 0.042, 0.002, 0.000, 0.035, 0.009 is a representation of VMT mix, which gives the percent of VMT accumulated by each of eight MOBILE5a vehicle classes. MOBILE5a uses this VMT mix to calculate a composite emission factor from the individual emission factors it calculates for eight different vehicle classes. The light duty truck and heavy duty vehicles have larger emission factors when compared to the light duty vehicles. Thus, if the percentage of VMT accumulated by the light duty trucks and heavy duty trucks is

increased, the increase in composite emission factor of the pollutant will be substantial. Hence, determining the change of VMT mix is essential in estimating the reduction in emissions due to TDM measures.

Table 1-2 MOBILE5a Vehicle Classification

Vehicle Class	Description
LDGV	Light Duty Gasoline Vehicle (Passenger Cars)
LDGT1	Light Duty Gasoline Truck 1 (< 6000 lbs)
LDGT2	Light Duty Gasoline Truck 2 (> 6000 lbs and < 8500 lbs)
HDGV	Heavy Duty Gasoline Vehicle (>8500 lbs)
LDDV	Light Duty Diesel Vehicle
LDDT	Light Duty Diesel Trucks (< 8500 lbs)
HDDV	Heavy Duty Diesel Trucks (> 8500 lbs)
MC	Motor Cycles

Some TDMs change the share of VMT accumulated by different modes[1] of transportation. VMT of each mode of transportation is assumed to be composed of VMT accumulated by different vehicle classes. This breakup of VMT of a particular mode of transportation in terms of VMT accumulated by different vehicle classes is known as vehicle fleet composition rate of that mode of transportation. To obtain the total VMT accumulated by a MOBILE vehicle class for a TDM scenario, the VMT accumulated by that vehicle class for each mode of transportation is aggregated. Thus the VMT mix is estimated. Since the TDMs change the share of VMT of each mode of transportation, the overall composition of VMT mix changes. To estimate the VMT mix changes, the vehicle fleet composition rates in terms of vehicle classes are used. The vehicle fleet

[1] The mode of transportation in TDM is defined by level of vehicle occupancy.

composition rates for different modes of transportation have been derived using the 1990 National Personal Transportation Survey (NPTS).

1.6 Organization of this Thesis

The remainder of this document is organized as follows: Chapter 2 presents a literature review of the work previously done in trying to link travel analysis tools and emission analysis tools. It also presents an overview of different travel and emission analysis tools available. Chapter 3 describes the development of algorithms and calculations used in the estimation of emission reductions. Chapter 4 describes in detail the process of derivation of vehicle fleet composition rates using NPTS data. Chapter 5 gives an overview of the TDMLinK software package. Recommendations for further research are discussed in Chapter 6.

2. LITERATURE REVIEW

2.1 Introduction

Interest in the analytical methodologies required to support transportation-air quality related analyses has occasioned a significant resurgence with the passage of the Clean Air Act Amendments of 1990. An important component of the Clean Air Act is the set of planning and analysis activities required by the states and designated nonattainment areas. CAAAs require State Implementation Plans (SIPs) to be submitted by all nonattainment areas. SIPs documents are of comprehensive nature that detail current emissions and air quality conditions, and demonstrate commitments to implement measures that are sufficient to achieve the national ambient air quality standards by a designated date [4].

Emission inventories are developed for all significant mobile, stationary, and area sources of pollutants, as part of an SIP. These inventories are developed for both a base year and a projected future year and provide the baseline condition against which the effectiveness of alternative control policies can be measured.

Stationary source inventories are also called the point sources and include the emissions from the industrial processes, waste burning, petroleum processes, solvent use and manufacturing. Area source emission is any combination of sources of emissions that are individually small, but are significant collectively. Some of area source emissions include residential housing heaters, commercial and industrial heaters and fireplaces. Mobile Source inventories include all transportation sources of emissions - "on-road vehicles" (automobiles, trucks and motorcycles) and "other vehicles" (off-road vehicles, trains, aircraft, marine and mobile/utility equipment).

Transportation plans and programs target the mobile source emission reductions in addition to the reductions offered by the strategies such as the Inspection and Maintenance programs, alternative fuels etc. Transportation Control Measures (TCM) are used as part of the transportation plans and programs. TCMs affect the home-based work trips the most.

2.2 Analysis Tools

Various analysis tools are available to quantify the effects of TCMs/TDMs on vehicle emissions. The travel analysis tools employ various methodologies to quantify the change in the speed, VMT and number of trips due to the TDM/TCM strategies. Some of the tools used are described in the following sections.

2.2.1 Travel Demand Management (TDM) Software

The TDM software model is an analytical tool that supports the design and quantitative evaluation of travel demand management strategies. This software was developed by COMSIS corporation for the Federal Highway Administration [5]. The TDM software model was developed on the basis of the nationwide research in TDM done by COMSIS. The first model was developed in the late 1980's and then it underwent several revisions. The model is used by several Metropolitan Planning Organizations (MPOs). A public domain version of the software is sponsored by the FHWA and is released through McTrans [6].

The TDM software operates on an IBM-PC compatible microcomputer. The software provides the user with a series of spreadsheets or worksheets where the user

specifies the assumptions about various TDM strategies. TDM allows the users to test the TDM measures either individually or as package of measures combined. On any one "run" of the model, up to four different program packages (known as scenarios) may be evaluated with no limitations on the number of strategies.

The TDM model was originally designed to aid the transportation planners in developing strategies to relieve congestion, with scope of application primarily at geographic subarea level. The intent of development of TDM model was to provide a tool which would be (1) a quick, reasonably accurate, and interactive "policy" tool, and (2) a device capable of providing quantitative estimates of TDM strategies, such as employer support measures and alternative work hours, which are not readily handled by existing transportation planning models. It implicitly assumes that the strategies are being analyzed for the morning peak home-based work trips. TDM model has been designed to communicate with the four step travel demand forecasting models. It uses the trip tables, produced by the four step travel demand forecasting models or user developed, as input and outputs trip tables modified due to TDM strategies.

A wide range of strategies can be tested in the TDM model. These strategies can be grouped under two categories:

1) Employer-Based Strategies (Ride-sharing promotions, alternative work schedules, and incentives and disincentives such as parking management, parking pricing etc.)
2) Areawide or Government-Applied Strategies (HOV lanes, Transit improvements, regulatory requirements, congestion pricing, etc.)

2.2.1.1 Computation Methodology

Three different procedures are used by TDM software to estimate the impacts of TDM policies. The TDM policies which can be translated into changes in time and cost are handled with a pivot-point version of the logit mode split model. The pivot point model takes the current modal shares for each origin-destination pair and adjusts those shares in relation to the particular strategy or strategies which are being applied. It does this through elasticity relationships. These estimated changes in share are fairly accurate for reasonable changes in travel time or cost, from the current starting point. TDM measures such as transit service improvements, High Occupancy Vehicle (HOV) priority lanes, preferential parking for HOVs, improvements in transit access, financial incentives and disincentives are evaluated using the pivot point model. Some of the TDM policies such as rideshare matching, guaranteed ride home, vanpool formation and support measures, etc., do not produce physical changes in travel characteristics, but act as a catalyst in causing the desired changes. These policies are evaluated through application of look-up tables. These tables contain factors which relate the probable change in modal share that would be likely to occur if a measure of the particular type were imposed.

The third group of strategies evaluated by the TDM model are work hours management actions. These strategies consist of flexible work hours, staggered work hours, compressed work weeks and telecommuting. To evaluate these measures, TDM software employs a combination of empirical look-up tables, proportioning of the work force, and manipulation of peak and off-peak travel times to estimate the impact. The empirical values and the look-up tables were derived from the extensive research done by COMSIS and others.

TDM software consists of six modes of transportation: 2-Person Carpool, 3-Person Carpool, 4-or-more-Person Carpool, Drive Alone(SOV), Vanpool and Transit. It

calculates the proportion of trips for 3 Carpool modes and Drive Alone mode on the basis of average vehicle occupancy. Average vehicle occupancy is estimated as the ratio of total auto persons to total auto drivers. VMT is estimated using the skim matrix (distance matrix) for the origin-destination pairs. VMT for each mode of transportation is obtained by multiplying number of trips made by that mode of transportation for a origin-destination pair, with the distance for the respective pair. The sum of VMT for all origin-destination pairs gives the total VMT for the particular mode of transportation.

2.2.1.2 Model Inputs

TDM software most commonly uses the same trip table information as is generated by the four step travel demand forecasting models. TDM requires information on person trips, vehicle trips and transit trips for each origin-destination pair. It also requires a distance matrix to compute VMT. TDM accepts the input tables in a variety of formats. TDM is compatible with MINUTP, TRANPLAN, and EMME/2 travel forecasting models. TDM has a capacity to process trip tables up to 1100 zones. However, the model is intended to run at a much smaller optimum size than this, with the optimum size being 200 to 1000 origin-destination pairs [5].

2.2.1.3 Model Outputs

For every run of the TDM model, revised set of trip tables (person, vehicle, transit) for each tested scenario are generated. TDM also produces summary output of the change in modal split, total VMT, and person, vehicle, and transit trips. A detail breakup of VMT and number of trips by level of vehicle occupancy is also given[1]. A sample output report produced by TDM software is shown in Figure 2-1.

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[1] Information about VMT and number of trips by each mode of transportation is available with only version 2.2A or later versions of TDM software.

*** Summary Report *** TESTING.RPT 9 Sep 1996

Test Scenarios

	PERCENT MODE SHARE					PEAK HOUR			% REDUCTION		
	DA	TRN	CP	VP	AVR	PERSON TRIPS	VEHICLE TRIPS	V M T	PERS TRIPS	VEH TRIPS	VMT
0	77.1	2.4	20.6	.0	1.15	7176	6240	8552			
1	69.9	3.6	26.3	.3	1.21	7134	5885	8060	.6	5.7	5.8
2	59.2	4.7	34.9	1.2	1.32	7062	5360	7337	1.6	14.1	14.2
3	48.8	5.8	43.2	2.2	1.44	6993	4854	6648	2.6	22.2	22.3
4	46.4	6.0	45.0	2.5	1.47	6974	4737	6486	2.8	24.1	24.2

Scenario Descriptions

0 Base Conditions
1 Trial 1
2 Trial 2
3 Trial 3
4 Trial 4

Trip and VMT Changes (Trial vs. Base)

		Base	Trial 1	Trial 2	Trial 3	Trial 4
SOV	Vehicles	5529	4989	4179	3410	3238
	VMT	7603	6858	5750	4698	4463
	% change	---	-9.8	-24.4	-38.2	-41.3
HOV 2	Vehicles	678	853	1121	1374	1425
	VMT	910	1150	1517	1864	1934
	% change	---	26.4	66.7	104.7	112.4
HOV 3	Vehicles	23	29	38	47	48
	VMT	28	35	46	57	59
	% change	---	25.7	67.3	106.4	114.5
HOV 4+	Vehicles	10	15	21	25	26
	VMT	11	18	24	29	31
	% change	---	58.3	111.8	162.1	172.7
Vanpool	Vehicles	0	1	7	13	15
	VMT	0	2	10	18	20
	% change	---	.0	.0	.0	.0
Total Auto	Vehicles	6240	5887	5359	4856	4738
	VMT	8552	8060	7337	6649	6487
	% change	---	-5.8	-14.2	-22.3	-24.2

Figure 2-1 Sample output report produced by TDM

Some of the abbreviations used in output report shown in Figure 2-1 are:

DA - Drive alone
TRN - Transit
CP - Carpool
VP - Vanpool
AVR - Average vehicle occupancy rate

The values for vehicle trips and VMT by different levels of vehicle occupancy are estimated using the trip tables produced for each mode for each scenario. However, the TDM software lacks provisions for estimating changes in vehicle speeds, operating mode mixes, or emissions that may result from the implementation of TDM measures.

2.2.2 MOBILE5a

MOBILE5a is a computer program that estimates hydrocarbon (HC), carbon monoxide (CO), and oxides of the nitrogen (NOx) emission factors for gasoline-fueled and diesel highway motor vehicles. The U.S. Environmental Protection Agency (EPA) has developed the model and is used in the preparation of all projection year emission inventories required by the Clean Air Act Amendments of 1990 for all areas except for California [7]. MOBILE5a is the latest updated emission factor model released by EPA in March of 1993. The MOBILE models are developed based on the data collected through various data collection programs that help quantify the rate at which pollutants are emitted by individual categories of motor vehicles under a variety of operating conditions [3]. MOBILE5a software is distributed through the EPA's Bulletin Board System (BBS) or National Technical Information Service (NTIS) of U.S. Dept. of Commerce.

MOBILE5a is available for three computer platforms: a) Mainframe, b) DOS-based microcomputer, and c) Apple Macintosh. The DOS-based version of MOBILE5a has been used for the purpose of this project. MOBILE5a accepts input in three different forms: interactive input, file input and batch file input. Interactive input requires extensive manual input with exact FORTRAN specification spacing, at the MOBILE5a prompt and is discouraged by the developers of MOBILE5a. Batch input file mode is used to execute multiple input files of MOBILE5a in a single run. File input requires preparation of an input file with the required parameters formatted with predefined specifications. MOBILE5a provides for testing various scenarios by changing values of some of the variables. The output file produced by MOBILE5a compiles emission factors for various pollutants by vehicle class and by each scenarios tested.

The estimation of emission factors is dependent on the base emission factors, effect of local conditions, characterization of vehicle fleet, the impact of fuel characteristics and the effect of inspection and maintenance programs. The base emission rates are developed from the in-use vehicles under the standardized conditions such as speed, starting conditions, temperature etc. MOBILE5a has a built-in database of these basic emission rates for vehicles operating under standardized test conditions. The model adjusts the base emission rates to reflect conditions other than the standard test conditions, through the use of correction factors. MOBILE5a also allows to estimate the emission factors for a wide range of emission control programs and fuel characteristics. These include: (1) Inspection and Maintenance Programs, (2) Anti-Tampering Programs, (3) Functional Pressure/Purge Checks, (4) Refueling Emission Checks, (5) Use of Oxygenated Fuels and (6)Use of Reformulated Gasoline

2.2.2.1 INPUTS

MOBILE5a has several groups of input variables which describe the vehicle fleet and operating conditions. Default values for some of the variables are incorporated into MOBILE5a and can be changed to reflect the local conditions of the study area. The groups of data can be classified as:

- Traffic flow data, such as speeds, cold start fractions, and vehicle types;
- Vehicle fleet data, such as age distributions and inspection/maintenance status;
- Fuel parameters, such as reformulated or oxygenated fuels and refueling controls; and
- Environmental variables, including temperatures.

2.2.2.2 OUTPUT

MOBILE5a outputs exhaust emission factors for each pollutant, expressed in gm/mi, for eight different vehicle classes. In addition to the exhaust hydrocarbon emission factors, evaporative HC emissions are also reported as g/mi or grams/event. A sample MOBILE5a output file is shown in Figure 2-2. As shown in Figure 2-2 the output report specifies the speed at which the emission factors for individual vehicle classes were calculated. It also provides the scenario specific conditions such as operating mode mix, temperature, etc.

```
1  Demonstration of IMFLAG 3 - 'midstream switch' in I/M models.
 MOBILE5a (26-Mar-93)
0I/M program #1 selected:                    I/M program #2 selected:

0Start year (Jan 1):  1983                   Start year (Jan 1):  1990
 Pre-1981 stringency: 20%                    Pre-1981 stringency: 20%
 First MYR covered:   1968                   First MYR covered:   1984
 Last MYR covered:    2020                   Last MYR covered:    2020
 Waiver (pre-1981):    1.%                   Waiver (pre-1981):    1.%
 Waiver (1981+):       1.%                   Waiver (1981+):       1.%
 Compliance Rate:     98.%                   Compliance Rate:     98.%
 Inspection type:                            Inspection type:
 Test Only                                   Test Only
 Inspection frequency: Annual                Inspection frequency: Annual
 I/M program #1 vehicle types                I/M program #2 vehicle types
      LDGV - Yes                                  LDGV - Yes
     LDGT1 - Yes                                 LDGT1 - Yes
     LDGT2 - Yes                                 LDGT2 - Yes
      HDGV - No                                   HDGV - No
 1981 & later MYR test type:                 1981 & later MYR test type:
      Idle                                        IM240 test
 Cutpoints, HC:   220.000                    Cutpoints, HC:     0.800
 Cutpoints, CO:     1.200                    Cutpoints, CO:    15.000
 Cutpoints, NOx:  999.000                    Cutpoints, NOx:    2.000

0Scenario title.                          Minimum Temp:  72. (F)        Maximum Temp:  92. (F)
                      Period 1 RVP: 11.5     Period 2 RVP:  8.7       Period 2 Start Yr: 1992
0VOC HC emission factors include all evaporative HC emission factors, except for refueling emissions.
0
0Emission factors are as of Jan. 1st of the indicated calendar year.
0Cal. Year: 1990       I/M Program: Yes      Ambient Temp: 87.5 / 87.5 / 87.5 (F) Region: Low
                Anti-tam. Program: No     Operating Mode: 20.6 / 27.3 / 20.6   Altitude:  500. Ft.
                 Reformulated Gas: No
0  Veh. Type:      LDGV     LDGT1     LDGT2      LDGT      HDGV      LDDV      LDDT      HDDV       MC    All Veh
+
 Veh. Speeds:     19.6      19.6      19.6                19.6      19.6      19.6      19.6      19.6
     VMT Mix:    0.655     0.161     0.082                0.031     0.009     0.002     0.052     0.008
0Composite Emission Factors (Gm/Mile)
 VOC       HC:    5.73      6.24      9.48      7.33      22.58      0.71      1.03      3.41      7.89     6.479
 Exhaust   HC:    2.12      2.79      3.97      3.19       8.44      0.71      1.03      3.41      2.38     2.626
 Evaporat  HC:    1.32      1.65      2.47      1.92       8.98                                    5.09     1.650
 Refuel    L HC:  0.27      0.35      0.37      0.36       0.60                                             0.282
 Runing    L HC:  2.20      1.71      2.96      2.13       5.02                                             2.111
 Rsting    L HC:  0.10      0.09      0.08      0.09       0.15                                    0.43     0.092
 Exhaust   CO:   31.14     36.36     42.42     38.40     177.59      1.67      1.97     13.88     25.13    36.130
 Exhaust   NOX:   1.70      1.97      2.53      2.16       5.81      1.63      1.93     21.74      0.77     2.964
0Evaporative Emissions by Component          Weathered RVP: 10.9          Hot Soak Temp: 88.6 (F)
 (Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr)   Running Loss Temp: 89.2 (F)
                                                                                  Resting Loss Temp: 82.5 (F)
 Hot Soak          8.00      9.40     15.25     11.26      29.49                                    19.89
 WtDiurnal        12.62     18.68     30.73     22.51      71.00                                    23.82
 Multiple         26.28     34.52     45.90     38.15      73.09
 Crankcase         0.02      0.04      0.16      0.08       0.39                                     0.00
 Refuel            5.55      5.55      5.55      5.55       5.55
 Resting           0.11      0.11      0.11      0.11       0.16                                     0.18
```

Figure 2-2 Sample MOBILE5a Output File

2.2.3 TCM TOOLS

TCM Tools is a software to quantify the travel and emissions benefits of individual TCMs [8]. TCM Tools was developed for the Federal Highway Administration by Sierra Research Inc. It is based on the different versions of software developed for California. TCM Tools is used for screening analysis of different TCMs being considered for a transportation project.

TCM Tools operates on a IBM-PC compatible computer. The software is comprised of three different programs known as modules. These modules allow the estimation of effect of TCMs on travel, emissions and cost. These modules are:

1. Transportation module: This module estimates the effects of individual TCMs on travel parameters such as speed, VMT and number of trips.

2. Emissions module: This module estimates the emission reductions due to the implementation of individual TCMs. This is performed by combining the results of the transportation module with the emission factors produced by MOBILE5a.

3. Cost-Effectiveness Module: This module combines the results from the emissions module and transportation module along with the costs of implementation of specific TCM to estimate the cost effectiveness of individual TCMs.

The three modules are designed to operate as stand alone tools; however, input for the emissions module and cost-effectiveness module are dependent on the output of previous module(s). The transportation and cost-effectiveness modules are Lotus 1-2-3 spreadsheet programs. The emissions module is a DOS program written in FORTRAN. TCM Tools has the capability of analyzing a broad range of strategies. These include the

TDMs, TSMs, facilities development and growth management. Also, the program allows to test a user-defined program, other than standard measures contained in the software.

Sketch planning techniques are used in the transportation module to estimate the travel related reductions of TCMs. For each measure, equations to calculate the effect on speed, number of trips and total VMT are embedded into the spreadsheet. Assumptions in the form of elasticities are used to estimate the change in parameters. The elasticity used in the equation depends on the parameter being estimated and on the measure being evaluated. One of the important elasticities used in the transportation module is the elasticity of speed with respect to volume. This elasticity has been used to estimate the percent change in the speed due to the implementation of a particular measure. The default values of the elasticities are provided in the software which can be changed by the user to reflect the local conditions. The elasticities were derived based on the study in the Houston-Galveston Area [9]. Input for each of TCM being evaluated is specified in the spreadsheet. Input required varies by the TCM being evaluated. The spreadsheet calculates the individual effects of each TCM for which the input has been specified. However, the software does not consider the interactive effect of multiple TCMs. The transportation module produces output files to be used as input by the emissions module and the cost effectiveness module, consisting of the travel data for each TCM implemented.

The emissions module comprises of three different programs to calculate the emission factors, to combine them with the travel activity data generated by the transportation module, and to estimate the pollutants before and after the implementation of the TCMs. MOBILE5a is used to create the emission factors that are representative of vehicle fleet operating in the specific community. The output files produced by MOBILE5a are used by POSTMOB5, a program developed specifically for FHWA, to sort and rearrange the emission factors into a input file. This new input file is used by

TCMEMISF model. TCMEMISF model, also developed specifically for TCM Tools, estimates the tons of pollutants before and after the implementation of each TCM, by combining the travel activity data output from the transportation module with emission factor estimates produced by POSTMOB5.

TCM Tools allows subfleet analysis of a vehicle fleet operating in a specific community. Subfleet analysis may be required when a vehicle fleet of a community is subjected to differential inspection/maintenance programs and/or change in fuel specifications etc. MOBILE5a emission factors for each subfleet are produced and are then sorted and unified into one input file using the POSTMOB5. The user inputs the subfleet specific input into the TCMEMISF model. TCMEMISF weighs the emissions obtained for each subfleet using the input provided by the user to estimate the composite emissions representing the whole vehicle fleet.

TCMEMISF provides the user with the option of calculating the effect of operating mode mix on the emission factors using either the Sierra methodology [10] or the methodology used by EPA in MOBILE5a model. The Sierra methodology eliminates the need to know the fraction of VMT in the cold start, hot start and hot stabilized modes, requiring only the number of trips starting cold. This methodology is detailed in Appendix A.

TCMEMISF produces an output file consisting of information about the reduction in emissions due to the implementation of each individual TCM measure. This output file is then used by the cost-effectiveness module along with travel activity data output file from the transportation module, cost parameters and TCM specific cost inputs to estimate the cost effectiveness of the TCM.

2.2.4 TCM Analyst

TCM Analyst is a sketch planning tool developed by Texas Transportation Institute for assessing the potential effectiveness of a TCM in terms of emissions and cost effectiveness [11]. TCM was developed by combining the elements of the methodologies developed by Systems Applications International (SAI) for the U.S. EPA [12] and the TCM Tools software. These methodologies have been shaped into a spreadsheet tool.

TCM Analyst uses the Microsoft Excel spreadsheet environment as a platform for TCM analysis. The software consists of about seven modules to perform various functions. These modules are the data input module, travel module, emission modules for CO and ozone, cost-effectiveness module, results module, and summary module. The data input module allows the user to specify the baseline conditions of the community and also the TCMs being evaluated. The other modules are used to estimate various parameters relevant to the module.

TCM Analyst is directed towards transportation engineers and planners who need to evaluate potential effectiveness of TCM implementation within their jurisdictions. The software has a regional scope of application rather than microscale level, and evaluates individual TCMs without considering the interactive effect of implementation of multiple TCMs. The travel module uses elasticities similar to the elasticities used in TCM Tools, to estimate the effect of TCM on trip/traffic effects. It uses the same elasticity of speed with respect to volume, as used in TCM Tools, to estimate the percent change in speed due to the implementation of TCMs. The travel module of the software requires wide array of data inputs which can be gathered from various census sources, travel surveys, travel demand models etc. TCM Analyst provides default data for many of the parameters but are required to be changed in order to represent the study region.

TCM Analyst uses MOBILE5a to produce emission factors for HC, CO and NOx. It then uses these emission factors to estimate the total change in pollutant emissions due to the implementation of TCMs. Estimation of total changes in emissions is performed as a four step process by accounting for the change in trips, VMT, idle and local speed changes, and fleet speed changes. Change in the number of trips causes change in the number of cold starts and hot starts, and hence a change in the operating mode mix. TCM Analyst estimates the effect of change in the operating mode mix using the SAI methodology. The procedure converts the emission factors for specific vehicle states into start emissions in grams per trip. The number of trips reduced and the start emission factors are used to estimate the change in the vehicle start emissions. In addition to the start emissions, change in hot soak emissions and diurnal emissions are calculated. All of these three emissions are summed to obtain the total change in emissions due to trip changes. Similar emission changes are estimated for VMT, idle and local speed change and fleet speed change. Finally all the components are summed to obtain the total emission changes due to TCM implementation.

The results reported by TCM Analyst include the travel and emission impacts and cost-effectiveness of the TCM evaluated. These impacts are reported in terms of changes in speed, VMT, number of trips, pollutant emissions, and gross and net cost-effectiveness of the TCMs. These results are reported both as sum of all the TCMs implemented and by individual TCMs.

2.3 Traditional Procedure for TCM Analysis

Traditional analysis of TCMs is performed using the sketch planning tools or detailed network analysis tools. The tool used is dependent on the level of analysis required to be performed. Sketch planning techniques are used to analyze the TCMs at a

more aggregate level than that of network analysis tools. Sketch planning methodologies use coefficients and elasticities to calculate the effect of implementation of TCMs on speed, VMT, the number of trips etc. Detailed network analysis is performed using the travel demand forecasting models e.g. MINUTP, EMME/2 etc. To assess the effect of the TCM implementation, the TDM software is used depending upon the applicability and availability. In the absence of TDM software, the TCMs maybe analyzed using sketch planning techniques. As the first step in the process of analysis, the travel demand forecasting model is run for the base conditions to obtain the base VMT, speed, total number of trips etc. Using the sketch planning techniques, the TCMs are analyzed based on the base input data available from the travel demand forecasting process. This process would give the modified travel parameters' values for the implementation of TCM. These values are then used to estimate new emission factors and finally the total emissions and reduction in emissions. The measures which directly affect the travel time and cost are analyzed by using travel demand forecasting models.

TDM software is designed to allow it to interact with the travel demand forecasting. The process of analysis using the TDM software is explained below. As explained for the sketch planning techniques, travel parameter values for the base conditions are obtained using the travel demand forecasting models. For analyzing the effects of the TDM strategies, the trip tables produced by modal split model of the four step planning model is input into the TDM software. Also, the user specifies the information regarding the TDM strategies being tested in the TDM software. As mentioned in section 2.2.1, TDM allows a user to test up to four TDM packages in a single run. TDM also produces as an output modified trip tables by mode for each of the TDM package tested. To obtain the modified average speed due to the implementation of the TDM package, the modified trip tables produced for that TDM package are input into the traffic assignment model of the four step planning model. The traffic assignment model outputs the modified average speed, VMT, and total number of trips. Thus, if a

user tests four TDM packages in a particular run of TDM, then four equivalent runs the traffic assignment model have to be made to determine the effect of each TDM package.

After obtaining the average speed, VMT and total number of trips for each package of the TDM are evaluated, and the corresponding emission factors are obtained using MOBILE5a. MOBILE5a uses the average speed of vehicle fleet for each TDM package evaluated to produce corresponding emission factors. The emission factors for all the TDM packages evaluated can be obtained in a single MOBILE5a run by appending data regarding each TDM package as a separate MOBILE5a scenario. The emission factors are also calculated for the base conditions using the base average speed. The emission factors obtained from MOBILE5a are in terms of grams per mile. To convert this emission factors into emissions in terms of grams, the emission factors are multiplied with the corresponding VMT. This process is performed for both base and TDM evaluated conditions. The difference between the base and modified emissions gives the reduction in emissions.

2.4 Evaluation of Transportation Control Measure Programs: Case Studies

In order to meet the various mandatory air quality and transportation requirements set out by the Clean Air Act Amendments, various metropolitan areas and non-attainment areas have developed transportation programs to implement TCM as part of their State Implementation Plans. These programs have been developed by the transportation planning agencies responsible for the development of SIPs for that region. Various methodologies have been used by different regions in evaluating the effectiveness of the TCM programs. Some of these programs were studied for the purpose of this research work. Two such programs are presented here. These programs involved the use of tools that were of interest for this research work. The Philadelphia region TCM program

demonstrates the use of TDM software in the evaluation of TCMs. The San Joaquin Valley TCM program uses the TCM Tools software, which was extensively referred in this research work.

2.4.1 Philadelphia Region TCM Program

A study was performed by COMSIS Corporation for the development of the SIP for the Philadelphia Region [6]. This study was performed under contract to Delaware Valley Regional Planning Commission (DVRPC) in 1994. The aim of the study was to evaluate and identify various TCM measures to be included in the State Implementation Plan to achieve 15% emission reductions.

A broad system of TCMs were evaluated for the SIP development. Since the traditional transportation planning process was not suitable to evaluate many of the TCMs, alternative means of evaluation were developed. TDM software was one of the means used to evaluate some of the measures. TCMs, such as transit service improvements, highway system changes, and pricing actions were evaluated using the mode choice feature of the conventional 4-step planning process, as they involve rather direct changes in the travel time or cost.

For the TCMs which could not be evaluated by the standard 4-step process, sketch planning methods were used to analyze them. For these measures, case specific procedures and methodologies were developed to arrive at a sound, defensible estimate of the probable impact of the measure on travel and emissions. In general, these methodologies involved: (a) judgments as to the key variables that were being affected by the measure, and the manner in which they would be affected; (b) construction of methodologies employing market segmentation methods, factoring and application of

empirical findings/relationships to fashion a forecast of the travel behavior change, and (c) translation of the relevant changes in mode split to changes in trips and VMT at a trip table level. The modified trip tables were then reassigned to the no-build highway network to obtain the travel impacts.

For some of the employer-based TDM and area wide TDM strategies, the TDM software was used in the evaluation process. The process used the trip table inputs from the DVRPC's regional model and was assessed by TDM software. The revised trip tables were processed by the DVRPC model for the highway network assignment. The output of the highway network assignment was used in the emissions estimation.

The travel changes estimated by the various methods mentioned above were used with Post Processor for Air Quality (PPAQ) and MOBILE5a to calculate the levels of emissions for the region with the TCM alternatives in effect. Estimates for alternatives were compared with the base case to produce the net benefit of the alternative. PPAQ software was used to perform number of operations, such as estimate the change in VMT, in speeds, or in the number of cold starting vehicles, or vehicle type mix. These parameters were calculated for each cell of the DVRPC model. These variables were then input into MOBILE model to obtain emission factors for the three pollutants by each cell. These emission factors were multiplied with their respective VMT, and summed up to produce the region emission estimate for the TCM alternative. These when compared with the base emissions gave the change in the emissions due to the TCM alternative. As a final part of the analysis of the TCM alternative, cost effectiveness of the TCMs were estimated. To perform the cost analysis, case specific procedures were developed and cost-effectiveness of each measure was developed. These estimates were based on the travel and emission reduction potential of the TCM versus the cost of implementation of the TCM.

2.4.2 San Joaquin Valley TCM Program

The San Joaquin Valley Air Basin is designated as a "serious" nonattainment area under federal ozone standards and is subjected to stringent requirements of the California Clean Air Act. A Transportation Control Measure Program was developed for the San Joaquin Valley to aid in the long range plan to reduce emissions of carbon monoxide and ozone precursors through TCM implementation [13]. The project consisted of analyzing various TCMs and providing a list of feasible TCMs for the San Joaquin Valley. The TCM program was developed by JHK & Associates along with Sierra Research, Inc. and Project Technical Group for various transportation planning agencies in the San Joaquin Valley. The list of feasible TCMs developed were included in the regional transportation plans of the November 1994 SIPs developed by these transportation planning agencies.

A wide array of TCMs were considered in the development of the TCM program. The TCMs considered were included from the TCMs listed in the Section 108(f) of the Clean Air Act Amendments and from the TCMs listed in the Air Quality Attainment Plan of 1991 for San Joaquin Valley. From this initial list, few TCMs were selected for evaluation of their applicability in the Valley. The key criteria for the selection of the TCMs was whether they were reasonably available for implementation in the Valley.

To evaluate the selected TCMs, California version of TCM Tools was used. The California version of the TCM Tools uses EMFAC7SCF2 and BURDEN7CP for estimating the vehicle emission and activity factors. TCM Tools was used to estimate the emissions and cost effectiveness impacts of each of the TCMs. The baseline travel characteristics and TCM Tools specific required parameters were obtained from an Technical Working Group, specifically created for the purpose. The transportation module of the TCM Tools was used to quantify the travel impacts of each individual measure, and the emissions module was used to quantify the impact of those changes on

CO and other emissions. These estimates were then used to develop the cost-effectiveness of each of the TCM. The cost-effectiveness developed for each TCM was used for the relative rankings of the TCMs.

2.5 Summary

Transportation plans and programs, targeting the emission reductions, are used as part of the SIPs. These transportation programs are being evaluated using various tools such as TCM Tools, TDM, and TCM Analyst. These tools employ various methodologies in evaluating the TCMs included in the transportation programs. Some of these methodologies are specific to the TCMs which are being evaluated. TDM software in its present form is used to evaluate the transportation impacts of TDM strategies. Evaluation of emission impacts of TDM strategies using TDM software is a long and tedious process. To use TDM software as a screening tool, an alternative analysis method needs to be devised, which is easy to implement and is less time-and labor-intensive than current procedures.

3. METHODOLOGY

In this research work, methodologies were formulated to predict the changes in the values of three travel parameters, due to the implementation of the TCMs. These parameters are: speed, operating mode mix, and VMT mix. Changes in the values of these have been considered to have significant effect on the vehicle emissions. This chapter provides the details of these methodologies used in the developed software, to estimate the emissions due to the changes in these parameters.

3.1 Overview of Methodology

This section presents an overview of the methodology used in TDMLinK to estimate the emission reductions, due to the implementation of the TCMs. The methodology uses the output produced by TDM software to retrieve VMT and number of trips, by each mode of transportation. This information is used to calculate the change in speed for each scenario, as explained in Section 3.3. Using the scenario speeds calculated and various other MOBILE5a related input, an input file is prepared and MOBILE5a is executed. The output produced by MOBILE5a is used to retrieve the exhaust and evaporative emission factors for each pollutant and for each TDM scenario evaluated. Operating mode mix and VMT mix for each scenario are estimated and applied to the emission factors produced by MOBILE5a. The process of estimation of effect of change in operating mode mix and VMT mix is explained in Sections 3.2 and 3.4, respectively. The resulting emission factors are used in estimating the total emissions and effective reductions for each TDM scenario. Figure 3-1 shows the overall methodology used in the estimation of emission reduction process.

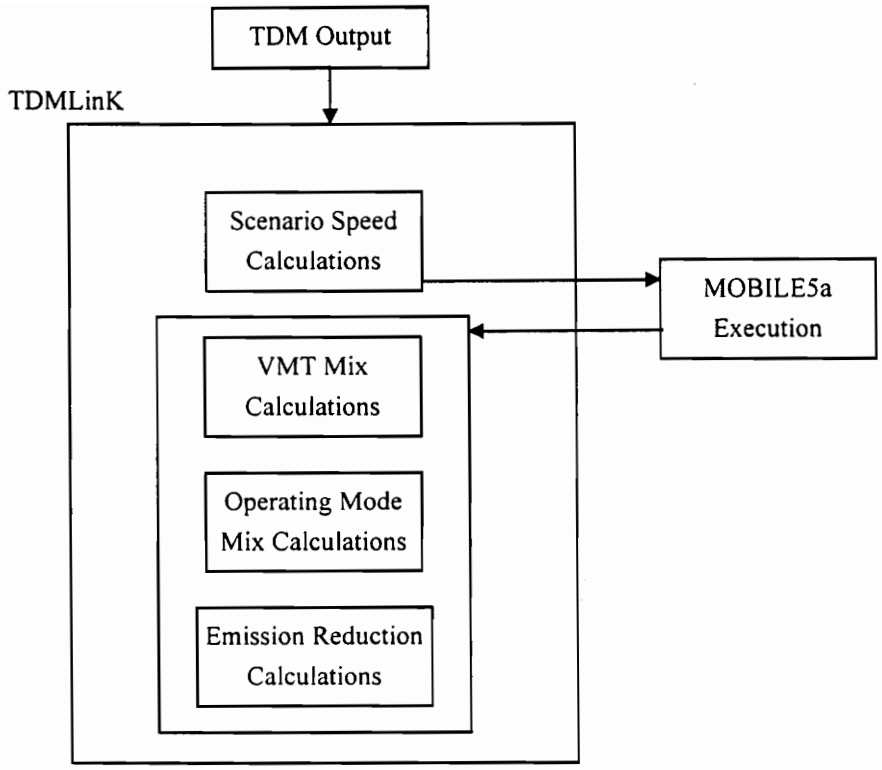


Figure 3-1 Overview of Emission Reduction Estimation Process

3.2 Operating Mode Mix

Emissions of hydrocarbons and carbon monoxide are significantly higher during the cold start engine operating mode, because of the low air to fuel ratios and poor performance of cold catalytic converters. MOBILE5a models the start emissions using the percent VMT in each operating mode. To develop an estimate of start related emissions using the traditional method, several pieces of information are needed. These include the following: a) percent of VMT that is in cold start operating mode, b) percent of VMT that is in hot start operating mode and, c) total VMT. Based on the estimates of percent VMT in each operating mode and the average speed, MOBILE5a estimates a

single emission factor for a pollutant. The product of this emission factor and the total VMT would give the total emissions in grams for a pollutant. Implementation of TCM alternatives have the effect of changing the total VMT. However, the change in total VMT may not be proportional to the change in the cold start VMT or hot start VMT. For example, park-and-ride measures produce total VMT reductions, but do not produce cold start VMT reductions. Estimation of percent of VMT in each operating mode after the implementation of the TCM may be either very tedious, requiring network assignment of each trip to determine the total VMT by mode and type of vehicle, or may not be feasible.

EPA tested vehicles using a standardized test cycle to estimate the emission factors produced in various operating modes. This test procedure was called Federal Test Procedure (FTP). It was determined that the cold/hot start portion of vehicle trip lasted for the first 3.59 miles of a trip. The vehicle then enters a hot stabilized operating mode. The emission factors for the hot stabilized mode were estimated to be lower than the emission factors for the cold/hot start operating modes.

A trip based approach to estimate the emission factors has been developed by Sierra Research [11]. In the Sierra Methodology, cold start emissions are assumed to be emitted instantaneously as soon as a vehicle is started. The cold start emissions are calculated as an offset. This cold start offset is assumed to occur irrespective of the length of the trip. The cold start offset is calculated by multiplying the difference of the cold start emissions and hot start emission with 3.59 miles (which is the length of the cold start portion of the Federal Test Procedure (FTP)). This gives the emissions in grams/trip. These emission factors are then multiplied by the total number of cold starts to get the total cold emissions in grams. The total number of cold starts are determined by multiplying the total number of trips with the percent known to be cold starts. The operating mode fractions of the trip VMT is assumed to consist of hot start transient and hot stabilized parts. These parts when combined is called running emissions. The

running emissions of the operating mode mix is calculated as a combination of the hot start transition and hot stabilized with 0.479 as hot start and 0.521 as hot stabilized. The running emissions factor is obtained as g/mi. The total running emissions in grams are obtained by multiplying the running emission factor with the total VMT. The sum of the total cold emissions and running emissions gives the total emissions for a particular TDM scenario. Calculation of emissions by using this methodology eliminates the need to know the fraction of VMT in different operating modes.

Dr. Venigalla [14, 15, 16] had developed a model to determine the start nature of a vehicle trip by time of day and trip purpose from the NPTS data. The model used the NPTS data to identify vehicles used for each trip, and whether the vehicle was equipped with catalytic converter or not. From the travel information provided, the cold soak period for each trip was determined using the end time and begin time of two successive trips. Depending on the vehicle type and the cold soak period, the start nature of each trip was identified. These trips were then classified by the time of day the trip started and also by trip purpose. From the data obtained by Dr. Venigalla, the percent of cold starts for the morning peak home-based work trips were estimated. The value, representing the national average, has been used to determine the total number of cold starts for each TDM scenario. This percentage is used by the TDMLinK software to estimate the total number of cold starts for each TDM scenario.

3.3 SPEED

Emission factors are sensitive to the average vehicle fleet speed input into MOBILE5a. In general, emissions tend to increase as average speeds decrease from 19.6 mph. HC and CO emission factors tend to decrease when the speed increases from 19.6 up to 55 mph [8]. However, the emissions increase as the speed rises over 55 mph. For

NOx, rise in emissions is almost flat when the speed increases from 19.6 mph to 48 mph. But for speeds above 48 mph, the rise in emissions are sharp. Change in the value of regionwide speed due to the implementation of the Travel Demand Management strategies is estimated using the elasticity of speed with respect to change in the volume, for peak hour traffic. The value of elasticity of speed used in the transportation module of the TCM Tools [9] software is used by the TDMLinK software. TCM Tools software uses two different elasticity of speed values to calculate the percent change in peak and off peak speeds. Since TDMLinK deals only with peak hour home-based work trips, the peak elasticity of speed with respect to volume is used. Speed for the base scenario is input by the user. Based on the base scenario speed, percentage change in speed for different scenarios are calculated using elasticity and the ratio of change in VMT to base VMT. Percentage change in speed is expressed in decimals. Following is the equation [8] used by TDMLinK:

Percentage change in speed = - [(Change in VMT)/(Base VMT)] * (Peak elasticity of speed with respect to volume)

The value of the peak elasticity of speed is a negative constant number. Change in VMT is defined as the difference of base VMT and the modified VMT. Thus if the change in the VMT is positive, then change in percentage speed is positive. Estimation of speed using a constant value with respect to volume is identified as a limitation of this research. Change in speed for a wide area varies by different factors, such as type of road facility, number of lanes etc. However, to simplify the estimation of speed over a wide area of network it was considered to be adequate.

3.4 VMT Mix

TDM software defines each level of vehicle occupancy as a separate mode of transportation. Some TCMs change the share of VMT accumulated by different modes of

transportation. VMT of each mode of transportation is assumed to be composed of VMT accumulated by different MOBILE vehicle classes. Thus VMT of each MOBILE vehicle class is obtained by summing the portion of the VMT accumulated by that vehicle class for each mode of transportation. Since the TDMs change the share of VMT of each mode of transportation, the overall composition of VMT mix changes. This can be better explained with an example. For example, let us assume that the VMT accumulated by Single Occupancy Vehicle (SOV) mode of transportation consists of 80 % of LDGV VMT, 10 % LDGT1 VMT, and 10 % of other vehicle class VMT, and Carpool mode of transportation consists of 60 % LDGV VMT, 20 % LDGT1 VMT, and 20 % of other vehicle class VMT. The total VMT for LDGV is obtained by summing the LDGV VMT portion of SOV, LDGV VMT portion of Carpool and LDGV VMT portion of other modes of transportation. If a TDM measure is implemented which increases the share of Carpool VMT and decreases that of SOV, then the sum of LDGV VMT for SOV and Carpool will be different from the original sum. Similarly the LDGT1 VMT will be different. Thus, to determine these changes in the VMT mix, composition rates of VMT of each mode of transportation were derived. This idea of deriving VMT mix based on composition rates is illustrated in Figure 3-2.

NPTS data was analyzed to develop composition rates of each mode of transportation in terms of MOBILE5a Vehicle classes. The vehicle composition rates of each mode of transportation is expressed as the percent of the total VMT accumulated by each MOBILE5a vehicle class, for that mode of transportation. The composition rates were developed in terms of LDGV, LDGT1, LDGT2 and HDGV vehicle classes. The sum of these composition rates for each mode of transportation is 100.0 percent. Derivation of the vehicle composition rates of SOV, Carpool and Vanpool using the NPTS analysis is explained in Chapter 4.

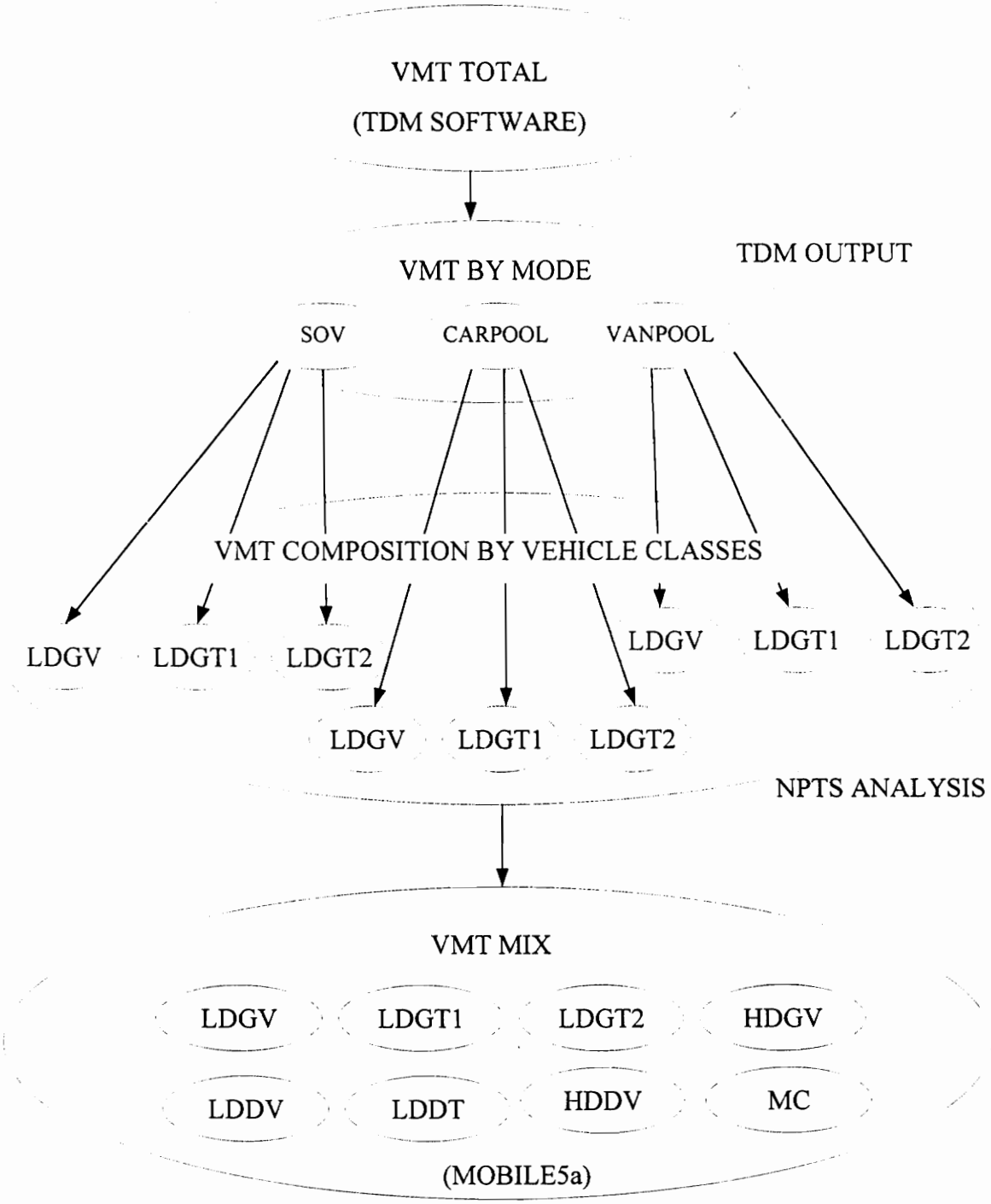


Figure 3-2 Vehicle Composition Rates to Estimate VMT Mix

The process of estimation of VMT mix in TDMLinK using vehicle composition rates is illustrated in Figure 3-3. In Step 1, VMT by mode of transportation is retrieved from the output of the TDM software. In Step 2, the vehicle composition rates of the three modes of transportation in terms of four gasoline fueled vehicle classes are specified. TDMLinK has the default vehicle composition rates derived from the NPTS analysis. The user is also provided an opportunity to change the default values to represent the local conditions. The vehicle composition rates matrix is then multiplied with the respective mode of transportation VMT in Step 3, to obtain a matrix in which the total VMT for each mode of transportation is classified by VMT for four vehicle classes. In Step 4, VMT accumulated by a vehicle class for each mode of transportation is summed, thus total VMT accumulated for four gasoline vehicle classes is obtained. The ratio of VMT of four vehicle classes results in the estimate of VMT mix consisting of four vehicle classes in Step 5. The values of the diesel vehicle classes are assumed as a percent of their gasoline counterparts. The value of MC class is assumed to be a constant for all the TDM scenarios. Default values for these assumptions are provided in TDMLinK which can be changed by the user to reflect the local conditions. Using the VMT mix of four gasoline vehicles and the percent of diesel vehicles comprising the gasoline vehicle counterparts, a composite VMT mix is then developed consisting of all the eight vehicle classes. This process of VMT mix estimation is performed for all the TDM action scenarios and the base scenario. Composite Emission factors are calculated for each TDM scenario using the respective MOBILE emission factors and the VMT mix developed.

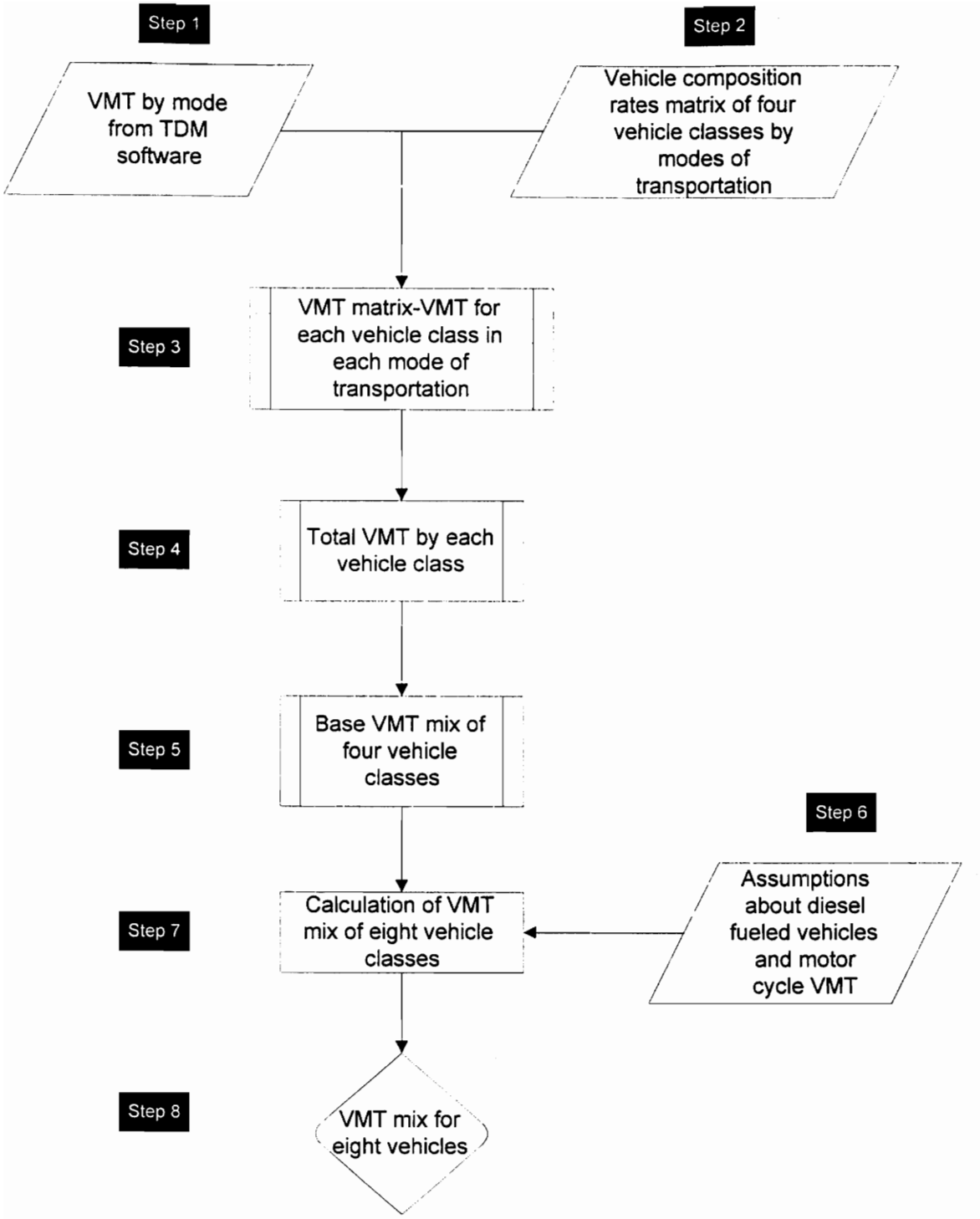


Figure 3-3 Process of estimation of VMT mix in TDMLinK

3.5 Calculation of Emission Reductions

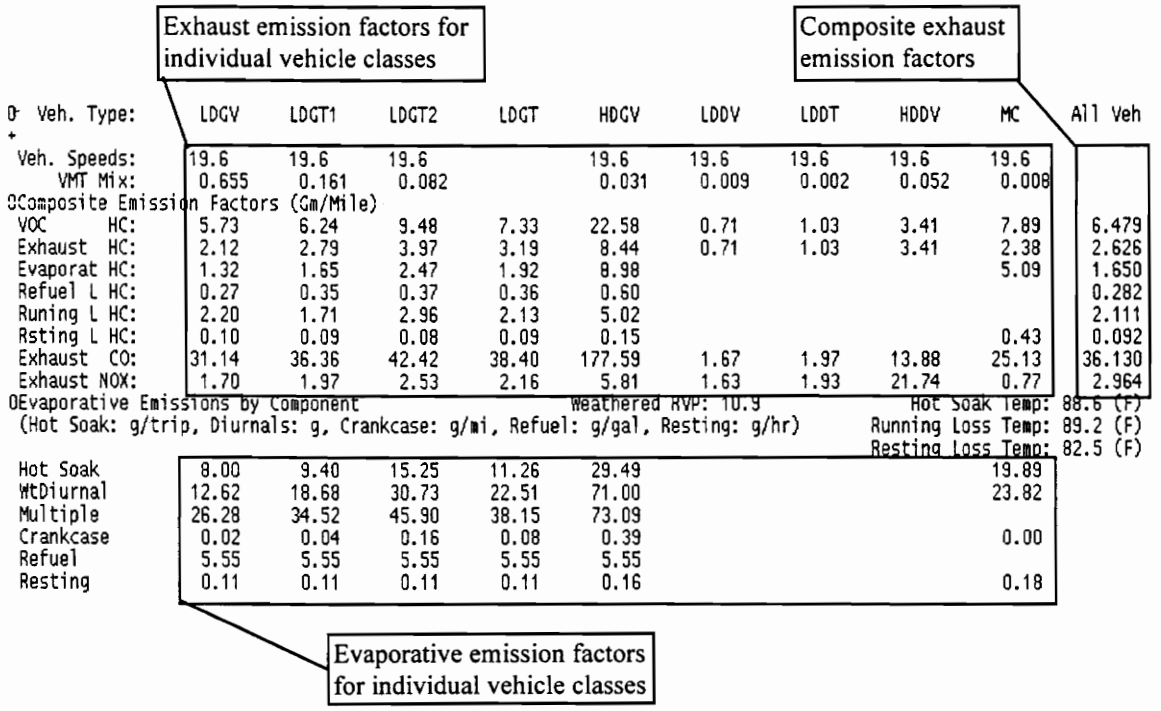
To estimate the reduced emissions due to change in the operating mode mix, three MOBILE5a scenarios are configured for base and each of the action TDM scenarios. In configuring the MOBILE5a scenarios, value of speed is estimated using the equation specified in Section 3.3. The following MOBILE5a scenarios are developed for each TDM scenario modeled.

1 100 % Cold start at TDM scenario speed calculated

2 100 % Hot start at TDM scenario speed calculated

3 47.9 % hot start/52.1 % cold start at TDM scenario speed calculated

MOBILE5a outputs emission factors by each class of vehicle. Figure 3-4 shows the various component emission factors calculated by MOBILE5a. These emission



Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
Veh. Speeds:	19.6	19.6	19.6		19.6	19.6	19.6	19.6	19.6	
VMT Mix:	0.655	0.161	0.082		0.031	0.009	0.002	0.052	0.008	
Composite Emission Factors (Gm/Mile)										
VOC HC:	5.73	6.24	9.48	7.33	22.58	0.71	1.03	3.41	7.89	6.479
Exhaust HC:	2.12	2.79	3.97	3.19	8.44	0.71	1.03	3.41	2.38	2.626
Evaporat HC:	1.32	1.65	2.47	1.92	8.98				5.09	1.650
Refuel L HC:	0.27	0.35	0.37	0.36	0.60					0.282
Runing L HC:	2.20	1.71	2.96	2.13	5.02					2.111
Rsting L HC:	0.10	0.09	0.08	0.09	0.15				0.43	0.092
Exhaust CO:	31.14	36.36	42.42	38.40	177.59	1.67	1.97	13.88	25.13	36.130
Exhaust NOX:	1.70	1.97	2.53	2.16	5.81	1.63	1.93	21.74	0.77	2.964

Evaporative Emissions by Component — Weathered RVP: 10.9 — Hot Soak Temp: 88.6 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) — Running Loss Temp: 89.2 (F)
Resting Loss Temp: 82.5 (F)

Hot Soak	8.00	9.40	15.25	11.26	29.49				19.89	
WtDiurnal	12.62	18.68	30.73	22.51	71.00				23.82	
Multiple	26.28	34.52	45.90	38.15	73.09					
Crankcase	0.02	0.04	0.16	0.08	0.39				0.00	
Refuel	5.55	5.55	5.55	5.55	5.55					
Resting	0.11	0.11	0.11	0.11	0.16				0.18	

Figure 3-4 MOBILE5a output report and emission components

components are output for each MOBILE scenario modeled. A composite emission factor is calculated for each exhaust emission category using the VMT for that particular scenario. From these emission outputs, for every TDM scenario, cold emissions offsets for every pollutant specified in the MOBILE5a input are calculated by each class of vehicle, as detailed previously in the operating mode mix algorithm. Composite emission factors for cold and running emission factors are calculated using the VMT mix for the respective scenario, estimated previously. The composite cold emission offset is then multiplied with the total number of trips for the respective TDM scenario and the percent of trips starting cold, to get the total cold emissions for the pollutant. The composite running emission factors are multiplied by the respective total VMT to get the total running emissions. The sum of the cold and running emissions gives the total emissions for the pollutant for the particular TDM scenario. This process is repeated for each of the pollutants specified in the MOBILE5a input. Percentage reductions of emissions by each pollutant are then calculated and are reported by the software. The relevant equations for the above computations are shown below:

Cold start emissions = Cold start offset * Total number of trips * Percent peak trips starting cold.

Running emissions = Running emission factor * Total VMT

Total emissions = Cold start emissions + Running emissions

Percent Reductions in emissions = [(Total base emissions - Total scenario emissions)/(Total base emissions)] * 100.0

The whole process of estimation of percentage reduction in emissions due to implementation of a TDM measure is illustrated in the Figure 3-5.

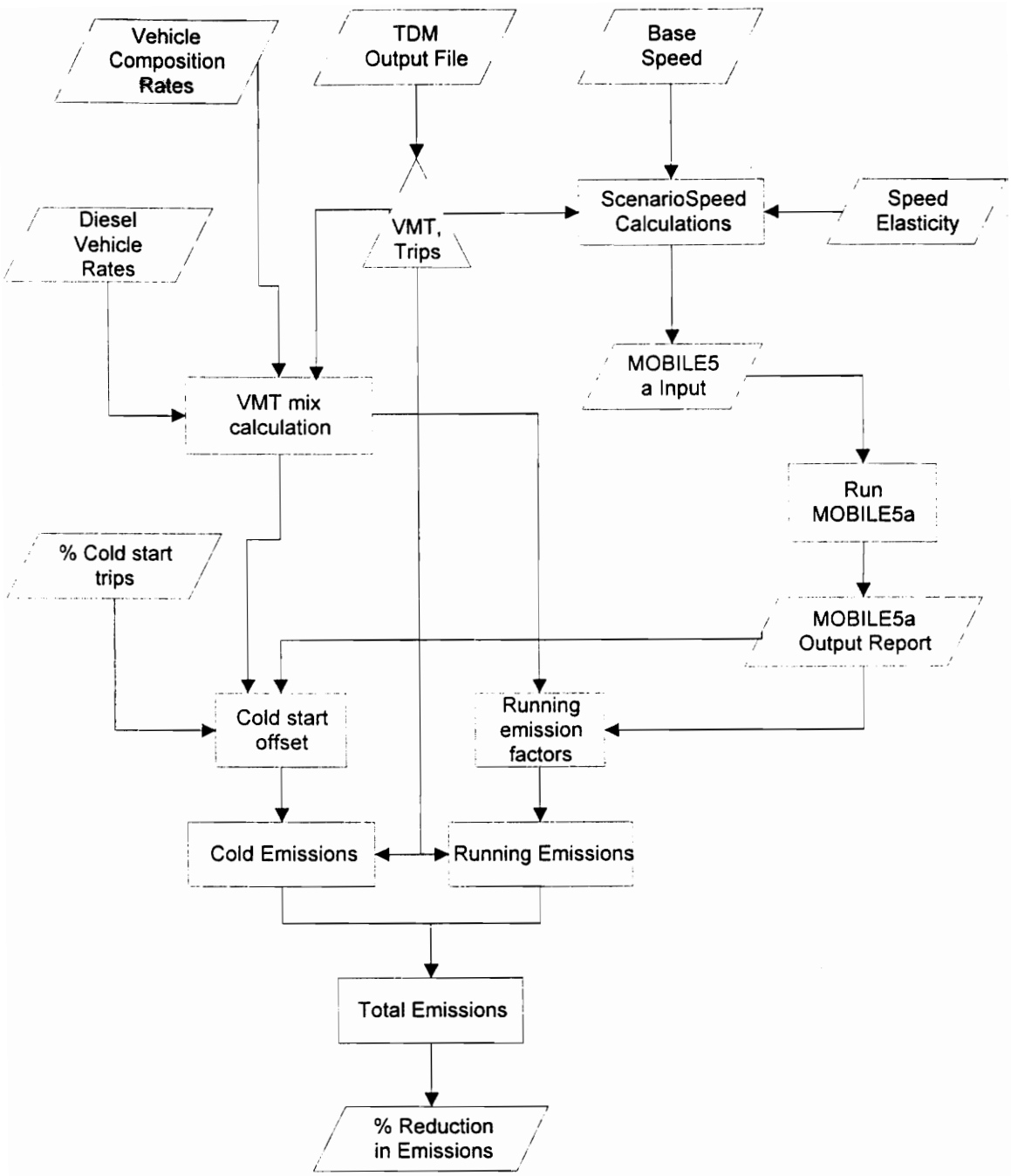


Figure 3-5 TDMLinK calculation process for estimating emissions reduction

4. Development of Vehicle Composition Rates to Estimate Change in the VMT Mix

4.1 Nationwide Personal Transportation Survey

The Nationwide Personal Transportation Survey (NPTS) compiles national data on the nature and characteristics of personal travel [17]. It addresses a broad range of travel in the United States, providing data on all personal trips for all purposes and all modes of transportation. The information collected as part of the survey included purpose of the trip, vehicle type, time of day, number of vehicle occupants for each trip etc. For the purpose of this project, the NPTS data set has been used to derive the vehicle composition rates for the trips having similar characteristics to those modeled in the TDM software.

The NPTS data is provided in the form of SAS data sets. The data is arranged in six hierarchical files to facilitate analysis. These files are classified based on the information available in each. The "Household" file contains household-level demographics such as geography and household composition. The "Person" file contains person-level characteristics for members of households that participated in the NPTS. The "Vehicle" file contains information about each vehicle in responding households. The "Travel Day" file contains specific information about each trip taken by respondents during the travel day. Travel day trips were classified as segmented trips if the respondent indicated that some mode of public transportation was used in the trip and a transfer from one vehicle to another took place while using the public transportation. For segmented trips, additional data was collected for each segment and appears in the "Segmented Travel Day Trip" file. All segmented trips are represented in both "Travel Day" files. The "Travel Period" file contains information about longer trips that took

place during the two weeks prior to a respondent's interview. Some key variables appear on multiple files in order to facilitate analyses without merging multiple files together. Also, these variables may be used to merge different files when the need arises.

The NPTS data set was available in the U.S. Department of Transportation's IBM mainframe computer. SAS was used to analyze the NPTS data in the MVS operating environment [18,19]. The "Household" file was used to retrieve the information on trips with particular characteristics. The "Vehicle" file was used to retrieve information on household vehicle, including the National Accident Sampling System (NASS) model code, NASS make code, model year, etc. The information in the "Daytrip" file was augmented by the information in the "Vehicle" file to derive the desired relationship. Table 4-1 shows some of the selected variables in the "Daytrip" and "Vehicle" files, along with a brief description and an indication of whether the variable was used in the analysis.

4.1.1 "Daytrip" file analysis

Scope of the TDM software is theoretically limited to AM peak home-based work trips. Thus the scope of analysis of the NPTS data set was limited to a set of observations which correspond with the limitations of the TDM software. To limit the scope of analysis, a set of criteria was developed. The selection of criteria involved certain implied assumptions. TDM strategies are generally applied in MSAs only, so non-MSA trips have been ignored. Trips made only by Private Owned Vehicles (POV) were considered and public transportation trips or trips by other modes of transportation were ignored. Also, the observations with uncertainty over household vehicle used for a trip and other information were discarded. The home based work trips were defined as a combination of trips to or from home and work related business trips originating from home, similar to the NPTS definition.

Table 4-1 Selected Variables In The NPTS Data Files [17]

DAYTRIP file

	VARIABLE	DESCRIPTION
	CMSA	Household location- CMSA
✓	DAYNIGHT	Indicates whether the trip has started during AM or PM
	HHLOC	Indicates the MSA status of the household location
		OR
✓	MSASIZE	Size of the MSA
✓	HHVEH	Household vehicle # used on the daytrip
	HH_ONTRP	Number of household members on the trip
	HOMEBASE	Gives whether it is a homebased trip or not.
✓	HOUSEID	Household Id
✓	NUMONTRP	Total number of persons on the trip
	NONHHCNT	Number of non-household members accompanying
	PARK_FEE	If parking fee was paid on the trip
✓	PEAKTRIP	If trip was made during peak hour.
	PUBTRANS	If public transportation has been used on the trip.
	SEGMENTD	If public transportation has been used on the trip and a transfer has
	TRANSFER	Change vehicles/means of transportation
✓	TRAVDAY	Travel day-day of week
	TRAVWKND	Travel day-weekend or weekday
	TRIPORIG	Origination point of trip
✓	TRIPPURP	Trip purpose classified as HBW, HB Shopping, Not home based
✓	TRPHHVEH	If a household vehicle was used on a daytrip
✓	TRPMILES	Length of the trip in miles
✓	TRPTRANS	Main means of transportation
	WHYTRP	Reason for the trip being made.

VEHICLE file

	CMSA	Household location- CMSA
	HHLOC	Indicates the MSA status of the household location
		OR
✓	MSASIZE	Size of the MSA
✓	HOUSEID	Household Id
✓	MAKECODE	NASS code for vehicle make
✓	MODLCODE	NASS code for vehicle model
✓	VEHID	Vehicle Id in a particular household
✓	VEHTYPE	Type of vehicle
✓	VEHYEAR	Model year of vehicle

✓ - Variable has been used in the SAS analysis

Initially, the observations in the "Daytrip" file were filtered to obtain trips with characteristics eligible for TDM analysis. The following criteria was used to get a base data set:

- Trips made in a MSA
- Trips made on weekdays
- Trips made during the morning peak period
- Home based work trips
- Trips made by private owned vehicles

The "Daytrip" file has a total of 149,546 observations. A base data set of 6,147 observations was obtained after screening, which formed the basis for further analysis. The screening procedure as shown in Figure 4-1 depicts the characteristics of the observations involved in the analysis.

4.1.2 Merging of Vehicle and Daytrip files

The base data set from the "Daytrip" file and the "Vehicle" file were merged to augment the trip observations with vehicle data. The merging of the two files was done using two variables HOUSEID and VEHID. HOUSEID is the household identification number included in all the observations in both "Daytrip" file and "Vehicle" file. VEHID is the vehicle identification number of a vehicle in a particular household, provided in the "Vehicle" file. The variable HHVEH in the "Daytrip" file is similar to the variable VEHID in "Vehicle" file, differing only by having an additional value range of 94, 98 and 99. The Value 94 indicates that no household vehicle was used on the trip. The values 98 and 99 represent either uncertainty or refusal of the respondent to specify which

household vehicle was used on the trip. Due to the similarity of the two variables VEHID and HHVEH, HHVEH was copied into a new variable named VEHID in the "Daytrip" file and was used as a merger variable.

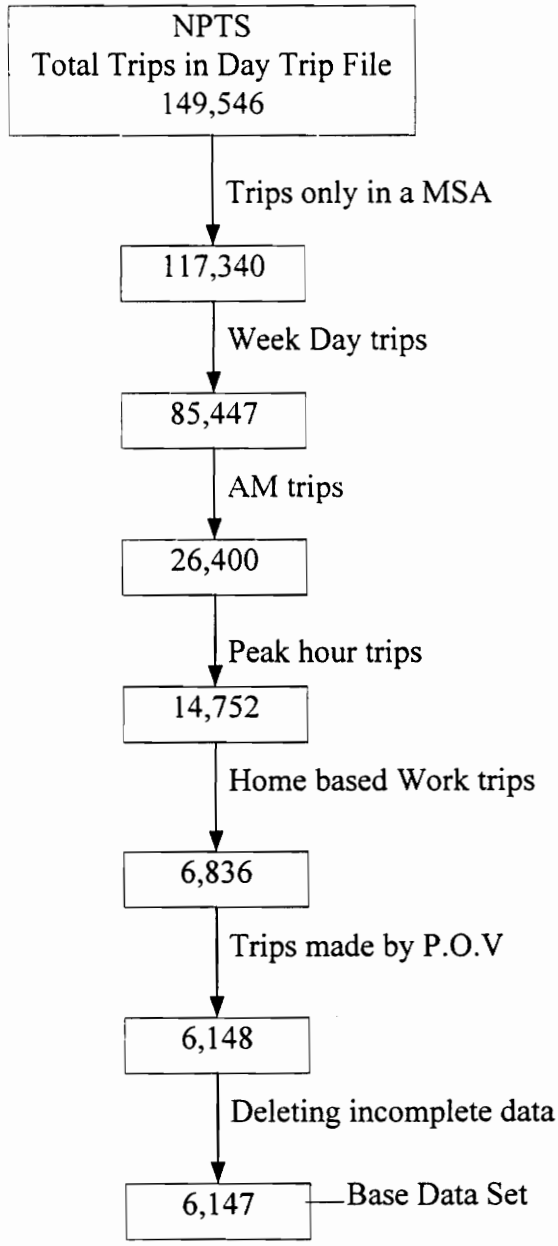


Figure 4-1 Filtering of Person Trips in the "Daytrip" File.

The merging methodology involved the coupling of observations in the base data set with the corresponding observations in the "Vehicle" file. The merging of the two files showed that there were certain inconsistencies with the variables TRPTRANS and VEHTYPE. TRPTRANS is a variable in the "Daytrip" file which identifies the type of vehicle being used on a particular trip. VEHTYPE is the variable in the "Vehicle" file which identifies the type of vehicle being detailed. The merger showed that about 315 observations in the set of 6147 observations had conflicting values of VEHTYPE and TRPTRANS. To avoid this conflict, it was decided after consulting with FHWA personnel who were familiar with the NPTS data set, to use the variable VEHTYPE specified in the "Vehicle" file, due to the higher confidence in the accuracy of information in VEHTYPE as opposed to variable TRPTRANS.

4.1.3 Data Organization

The model code and make information obtained from the "Vehicle" file was used to classify the vehicle. The base data set contained 353 observations for which the model code had value 'unknown', thus making it ambiguous for vehicle classification. The base data set showed that there were about 347 observations for which a non household vehicle was used. NPTS collected detailed vehicle information only for household vehicles and was recorded into the "Vehicle" file. Thus, no vehicle information was available for the trips which were made by non-household vehicles. Hence, a decision was made to segregate the data into three subsets.

Data Set #1: Household vehicles

This data set contains the observations in which household vehicles have been used to make the trips and have defined vehicle characteristics like model code and make code. This data set had 5447 observations.

Data Set #2: Household vehicles with missing vehicle characteristics.

This data set contains the observations in which household vehicles have been used to make the trips, but the vehicle characteristics such as the make code and model code have not been defined. Without this information it is not possible to classify the vehicles by their weight. But the variable VEHTYPE of these observations classifies them as auto, passenger van, etc. The size of this data set was 353.

Data Set #3: Non household vehicles

This data set contains the observations in which non-household vehicles have been used to make the trips. NPTS data set only describes them based on broad categories such as auto, passenger vans etc. The size of this data set was 347.

A comparative analysis was done on the three data sets to characterize each and to decide if separate analysis of two smaller data sets was required to develop relationship for each different data set. The first comparison performed was for average vehicle occupancy and average trip length by mode of transportation. The second part of evaluation was performed by comparing percentages of vehicle types by vehicle occupancies. The results of the analysis of the three data sets indicated that the characteristics of the household data set with missing model codes were very similar to that of larger household data set. The differences between the non-household data set and household data set were large enough to warrant a separate analysis of the non-household data set. The detailed process of analysis is shown in Figure 4-2, also indicating the number of observations involved in each process.

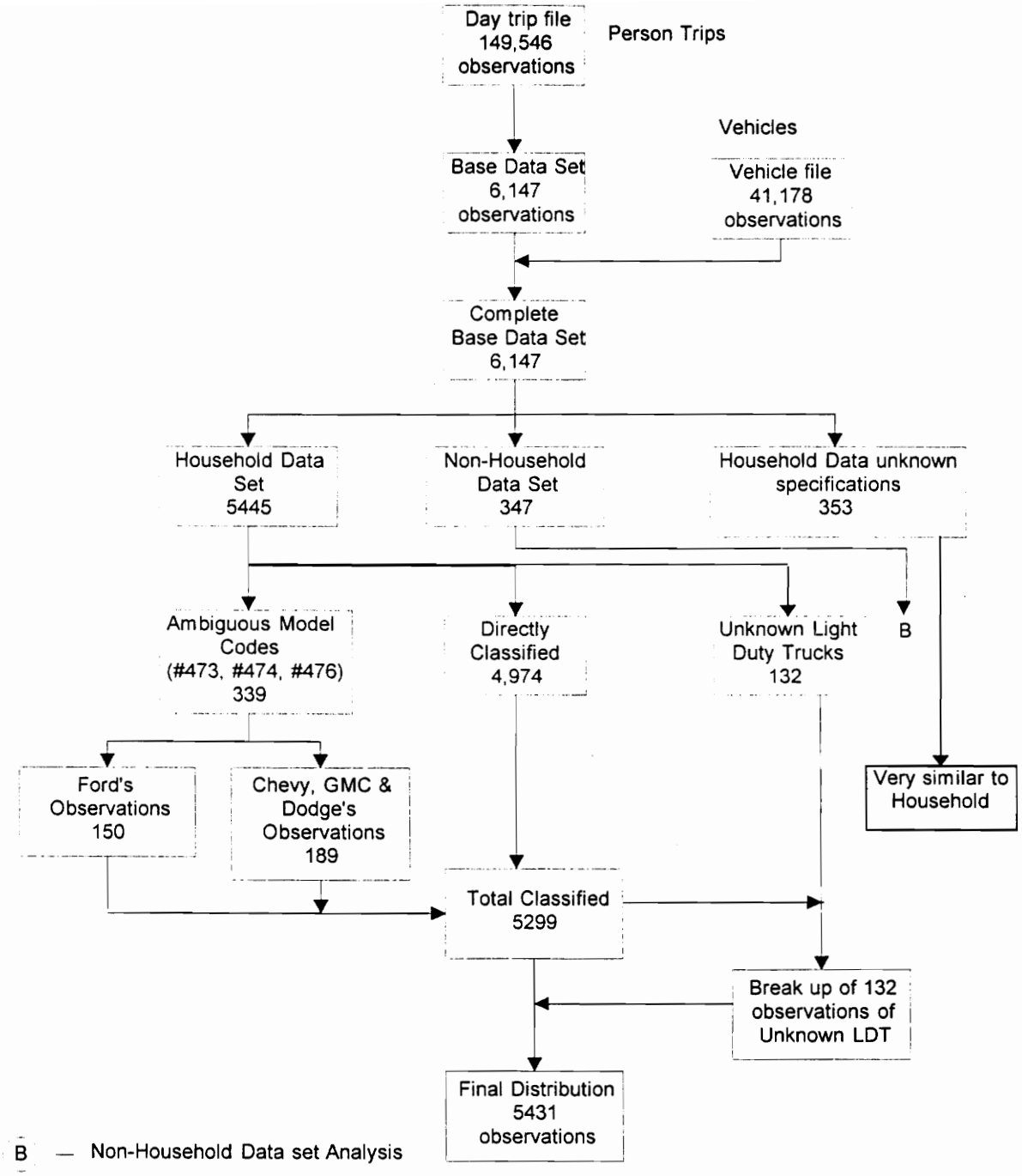


Figure 4-2 NPTS (1990) Analysis Process

4.2 Household Data Set

Vehicles in the NPTS were referenced using National Accident Sampling System (NASS) model codes. NASS is operated by the National Center for Statistics and Analysis (NCSA), which is part of the National Highway Traffic Safety Administration (NHTSA). NASS developed vehicle make and model codes to maintain crashworthiness data system and their General Estimate System. Model Codes are assigned to all the vehicle series sold in the US depending upon the body shape, functionality etc. For the purpose of this project NASS model codes were classified according to the MOBILE vehicle classes: Light Duty Gasoline Vehicles (LDGV), Light Duty Gasoline Truck 1 (LDGT1), Light Duty Gasoline Trucks 2 (LDGT2) and Heavy Duty Gasoline Trucks (HDGV). Classification was based on the vehicle make, model year and their corresponding vehicle specifications obtained from Ward's Automotive Year Book [20]. However some of the model codes could not be directly classified as belonging to a single MOBILE vehicle class. These model codes had a series of vehicle models that had ranges of Gross Vehicle Weights (GVW) that could fall into different classes used in MOBILE. This was particularly true in the case of pickup trucks and passenger vans with a range of models in a series. For example, the Ford F-series pickup trucks have wide series of models ranging from F-150 2-wheel drive to F-350 4-wheel drive. The F-150 model pickup trucks classify as LDGT1 whereas a F-350 would classify as a HDGV. Some of the models in between F-150 and F-350 classify as a LDGT1. Thus the classification of the model code containing F-series pickup trucks was ambiguous. The observations with model codes having problem were classified separately. A total of 339 observations had model codes whose classification was ambiguous. These trips were made by vehicles manufactured by Ford, Chevrolet, GMC and Dodge. There were also 132 observations which had no information on series or model to which the vehicle belongs, but were simply coded as a light duty truck of a particular make.

A new variable called CLASSIFY was created in the household data set. It was assigned a value depending on the Model Code classification of the corresponding observation. The classification of the Model Code consisted of LDGV, LDGT1, LDGT2, 473, 474, 476, 498 and OTHER. Values LDGV, LDGT1 and LDGT2 show direct representation of the model codes into MOBILE5a Vehicle classification. The values 473, 474, 476 and OTHER, represented the ambiguous model codes. The value 498 represented the observations with light duty trucks with unknown specifications. The vehicle occupancy levels were classified as SOV, CARPOOL and VAN. SOV consisted of vehicles with single occupancy. The value CARPOOL consisted of vehicle occupancies of 2 to 5 persons and value VAN consisted of a vehicle occupancy of six or more persons. The household data set was tabulated with CLASSIFY as the row attribute and Vehicle Occupancy as the column attributes. The intersection of a row with a column would give the number of observations with the specified vehicle occupancy and class of vehicle. Such tables were produced for trips made by each vehicle make. Thus, the end result was a set of tables which would give the number of trips made by a vehicles belonging to specified vehicle class, with specified vehicle occupancy, made by a particular vehicle manufacturer. The rows with values of CLASSIFY as 473, 474, 476 were retrieved from the tables of Chevrolet, GMC and Dodge, and were summed up and are shown in

Table 4-2. Similar table was obtained for the trips made by Ford Vehicles. Table 4-3 shows trips which were directly classified using model code and make code.

Table 4-2 Distribution Of Trips From NPTS w.r.t. Vehicle Occupancy For Chevy And Dodge

Model Code	SOV	CARPOOL	VAN	TOTAL
473	104	6	1	111
474	52	9	0	61
476	16	1	0	17
Total	172	16	1	189

Table 4-3 Vehicle Distribution From NPTS

	SOV	CARPOOL	VAN	TOTAL
LDGV	3636	479	2	4117
LDGT1	719	62	4	785
LDGT2	49	9	0	58
HDGV	0	0	0	0
	4404	550	6	4960

4.2.1 Vehicle Manufacturers' Data

To augment the incomplete vehicle coding information provided in the NPTS data set, various data sources of light duty truck sales and registration data were utilized. Each of the domestic manufacturers of the light duty trucks were asked to provide sales data for the model series of light duty trucks which were in question, for model years 1987 through 1994. Detailed letters were sent to Ford, Chrysler and Chevrolet and GMC divisions of the General Motors company. The quantity of data requested caused some reluctance on the part of manufacturers to render the data. Chevrolet's and Ford's light trucks comprised 38% and 45% respectively, of the total trucks with ambiguous model codes, thus their data was considered essential. Chevrolet provided US national registration data (without government registrations) for its line of light duty trucks for model years 1990 through 1994 [21].. This data had a satisfactory level of detail. Ford was unable to provide the sales/registration data, instead provided production data for model years 1984 to 1994 [22]. The data provided by Chrysler did not provide the required level detail and was not used in the analysis[23]. GMC and Chevrolet light duty trucks have similar characteristics and belong to the same parent company, thus Chevrolet's truck data was used to approximate the GMC's light duty trucks in the absence of GMC data. Dodge light duty trucks comprised only 7% of the ambiguous data. Since Chevrolet's truck data consisted of registrations instead of productions, it was used to approximate the Dodge's light duty truck registrations. From the available data

of Ford and Chevrolet the 1990 model year data was used in the analysis as it was closely corresponding to the 1990 NPTS data.

The values in

Table 4-2, Table 4-3, and a similar table representing Ford trips were imported to a Lotus 1-2-3 spreadsheet from the mainframe for further analysis. The manufacturer's data was analyzed to obtain percentages to disaggregate each Model Code into LDGT1, LDGT2 and HDGV. For each ambiguous model code a the vehicle series and the various models in the series were identified. The models in the series were identified according to the MOBILE vehicle classification system. For these vehicle classes the total sales/registration figures were summed. From this figures what percentage of the model code each vehicle class makes up was estimated. These percentages were multiplied with respective model code trips to obtain trips in terms of LDGT1, LDGT2 and HDGV. The process was performed on Ford's Vehicle table and

Table 4-2 shown above. Total trips were then obtained by adding Ford's classified data, Chevrolet's classified data and directly classified data from Table 4-3. From the resulting data, percentage of LDGT1, LDGT2 and HDGV vehicle classes of the total light duty truck data was obtained. These percentages were used to divide the trips which were classified with the model code 498, vehicles known to be light duty trucks. The results were then added to the previously classified data to obtain the final distribution, as shown in Table 4-4. Then final percentage break up of each mode of transportation in terms of Vehicle classification is shown in Table 4-5.

Table 4-4 Final Distribution Of Trips

	SOV	CARPOOL	VAN	TOTAL
LDGV	3636	479	2	4117
LDGT1	928	94	5	1027
LDGT2	192	26	1	219
HDGV	60	8	0	69
	4816	607	8	5431

Table 4-5 Final Percentage Distribution

	SOV	CARPOOL	VAN	TOTAL
LDGV	75.50	78.91	25.00	75.81
LDGT1	19.27	15.41	58.74	18.91
LDGT2	3.98	4.29	11.82	4.03
HDGV	1.24	1.39	0	1.26
	100	100	100	100

4.3 Non-Household Data set

The non-household data set was classified using the variable TRPTRANS since the "Vehicle" file didn't have information on the trips made by non-household vehicles. Thus a broad classification by auto, passenger van, pickup truck etc. was obtained. The particular characteristic of interest in the non-household data set were the vanpool trips.

To establish the characteristics of the vehicles being used for Vanpool trips, assistance was sought from VPSI Commuter Vanpool [24]. VPSI Commuter Vanpool is one of the nations largest third party vanpool service providers. It has a total fleet of approximately 3700 vehicles. Data regarding the fleet composition, vehicle specifications, vehicle occupancy, average trip lengths, etc. was provided by VPSI. This data was used to classify the vanpool trips made by non-household passenger vans.

4.4 Limitations

The following limitations have been identified in the development of the vehicle composition rates using NPTS and vehicle manufacturers' data:

1. Complete data for non-household vehicles is lacking.
2. The data provided in the NPTS cannot be directly classified into different vehicle classes.
3. A combination of production and registration data have been used to approximate the light duty truck data.
4. Lack of data from Dodge and GMC.
5. Vehicle Occupancy has been classified as SOV, CARPOOL and VAN. This has to been done due to lack of sufficient data on the components of High Occupancy Vehicles (HOV).
6. Number of Vanpool trips in both household and non-household trips are small.
7. Final vehicle composite rates do not include the non-household vehicle data.

5. SOFTWARE

5.1 Introduction

A software application has been developed linking the TDM software and the MOBILE5a. The software has been named TDMLinK, to signify the linkage between the TDM software and MOBILE5a. TDMLinK has been developed using Visual Basic for DOS in the MS-DOS environment. TDMLinK has been designed to run separate from the TDM software and also in a iterative process with it. TDMLinK incorporates methodologies discussed in Chapter 3 to estimate the effect of change in the value of the travel parameters due to the implementation of the TDM measures. Default values of various assumptions involved in the estimation of these travel parameters, such as elasticity of speed, vehicle composition rates etc., are provided and the user is given a option to alter the values to represent the local conditions.

TDMLinK can be installed on any IBM-PC compatible microcomputer. The hardware requirements of the TDMLinK are similar to that of the TDM software. TDMLinK is designed for DOS environment and requires an MS-DOS 3.1 or greater operating system. For Visual effects a VGA color monitor may be desired.

5.2 Execution of TDMLinK

A series of steps have to be executed to estimate the percent reductions in emissions due to TDM implementation, using TDMLinK. These steps are shown in Figure 5-1. Initially the TDM software is executed with the desired TDM packages various number of TDM scenarios. The output report produced by the execution of the TDM software is utilized by the TDMLinK. In Step 1 of the application of TDMLinK,

the output file generated by TDM is taken as an input and, the VMT and trips by each mode of transportation for various TDM action scenarios are retrieved. These values are then used to calculate the VMT mix. In Step 2 the MOBILE5a input parameters are specified by the user.

TDMLinK provides a graphical user interface (GUI) to prepare a MOBILE5a input file. A structured format is provided to input the various parameters required for the MOBILE5a execution. Input for the "Control" section, "One-Time" section and the scenario section can be edited by going through a series of screens. The required data for "One-Time" section and scenario section is dependent on the "Control" section flags. The software also gives the user an option of opening a MOBILE5a input file edited outside the application. Input for some of the control flags are restricted if using the graphical interface of the software. TDMLinK does not provide an opportunity to input interactively the factors for new basic emission rates, tampering rates, mileage accumulation and registration rates. These limitations can be overcome by editing the MOBILE5a input file, with appropriate flags and factors, outside the application and then opening it in the application. Also, with the objective of linking TDM and MOBILE5a, allowable values for many of the flags in the "Control" Section have been restricted. These flag restrictions have been listed in Section 5.4.2.2.1.

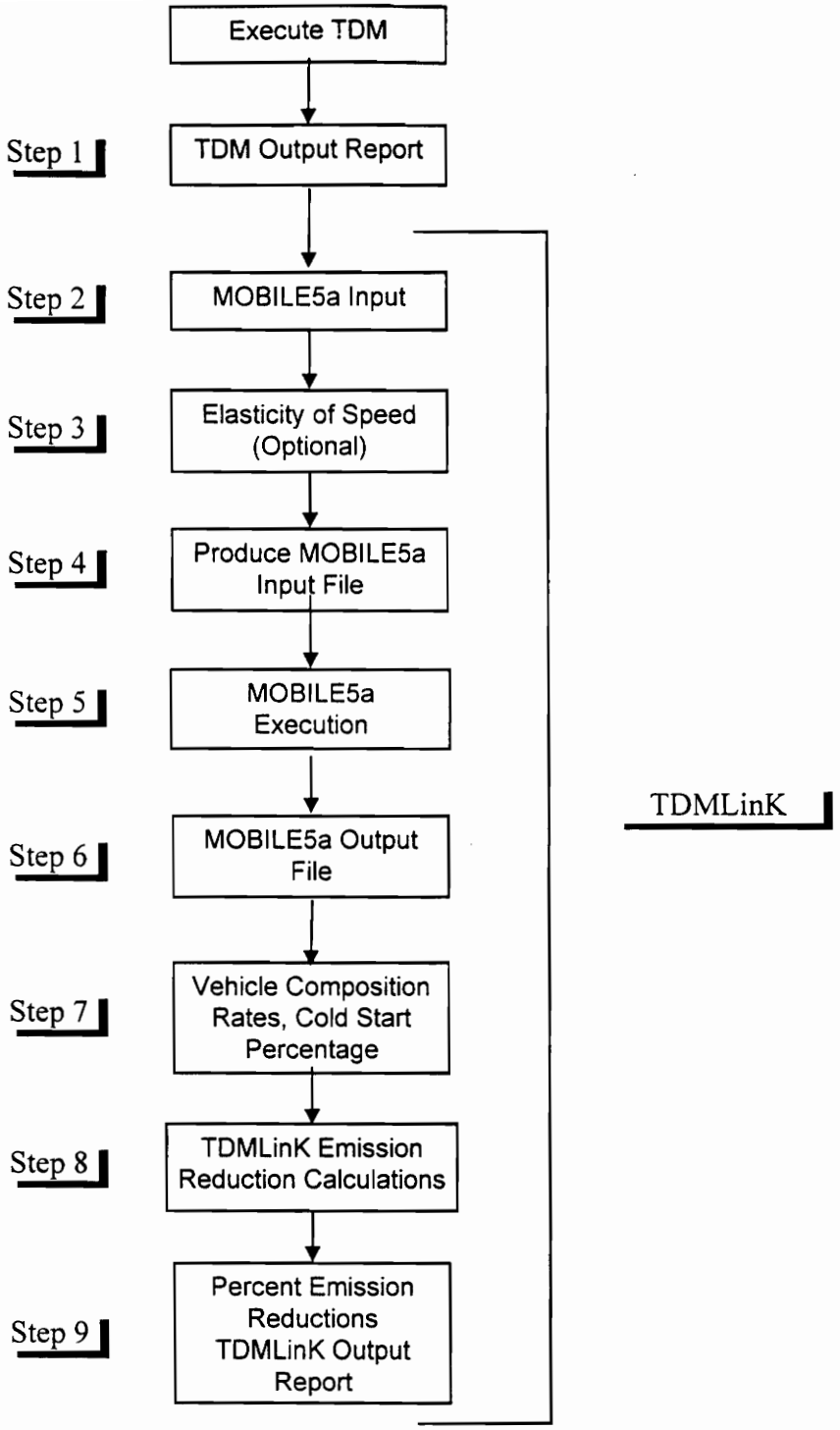


Figure 5-1 Execution Process for TDMLinK

A base scenario data for MOBILE execution is specified by the user. This base scenario data is used in the generation of additional MOBILE scenarios. Also when a saved MOBILE5a file is opened in the application the first scenario is read as the base MOBILE scenario and other scenarios are ignored. The user then can change the default value of elasticity of speed, if desired, as Step 3. Using the input provided by the user a MOBILE input file is generated by TDMLinK. While generating the input file average speed for all the action scenarios is calculated using the base scenario speed. Using these average speeds and the other base scenario data additional MOBILE scenarios are developed for each action TDM scenario evaluated in the TDM output report, using the methodology discussed in Section 3.5.

In Step 5 MOBILE5a is executed using the TDMLinK command. TDMLinK provides the user with help prompts for input commands of MOBILE5a. In Step 6 TDMLinK uses the output file produced by MOBILE5a to retrieve the emission factors for various scenarios and pollutants. Optionally the user can change the default values of vehicle composition rates and cold start percentage rate in Step 7. These values are used in the estimation of the VMT mix and the cold start emissions calculations respectively. TDMLinK then calculates the percent emission reductions using the calculation methodology explained in Section 3.5. Emission reductions are calculated for each pollutant for each TDM scenario modeled. As a final step TDMLinK scenario generates an output file listing summary of the process of TDM evaluation. A sample output report is shown Figure 5-2.

TDMLinK has a provision to calculate the percent reduction in emission in an iterative process. At the end of the emission reduction estimation process TDM software can be executed using a TDMLinK command. In TDM software appropriate input changes are made and a output file is produced. At the end of execution of TDM the

control returns to TDMLinK and a new process of TDMLinK input starts. This iterative process can be executed till satisfactory results are obtained.

```
                    ------------------------
                    TDMLinK OUTPUT REPORT
                    ------------------------

                         WASHINGTON, DC EXAMPLE

TDM OUTPUT FILE          :  C:\TDM\VBSYNG.RPT
MOBILE5A INPUT FILE      :  C:\M5A\ATP8.IN
MOBILE5A OUTPUT FILE     :  C:\M5A\ATP8.OUT
TDMLinK REPORT           :  C:\VBDOSPRO\PROGRAMS\SAVE1.TMO


    PERCENT MODE SHARE        P E A K   H O U R
   -------------------    -------------------------
                            PERSON  VEHICLE
     DA  TRN   CP   VP      TRIPS    TRIPS     V M T
   ----- ---- ---- ----    -------  -------   -------

0  58.8 19.9 21.3   .0    4980193  3413871   7678967
1  57.4 21.9 20.7   .0    4980193  3329979   7498349
2  54.4 26.5 19.1   .0    4980193  3146815   7177430
3  55.1 25.5 19.4   .0    4980193  3187801   7255537
4  47.5 36.3 16.2   .0    4980193  2739341   6330928


          % REDUCTION IN TRAVEL AND EMISSIONS
          -----------------------------------

               TRAVEL                EMISSIONS
          -----------------    -----------------
          PERS   VEH           TOTAL
          TRIPS TRIPS  VMT      HC    CO    NOx
          ----- ----- -----    ----- ----- -----
     0
     1      .0   2.5   2.4      3.7   3.9   2.3
     2      .0   7.8   6.5     10.2  11.2   6.0
     3      .0   6.6   5.5      9.0   9.5   4.8
     4      .0  19.8  17.6     25.2  27.9  16.8


           HC EMISSION COMPONENTS % REDUCTION
           ----------------------------------

                        Base   Trial 1 Trial 2 Trial 3 Trial 4
                       ------- ------- ------- ------- -------
Cold Start Emissions      0.0     1.4     3.8     3.4     8.9
Running Emissions         0.0     1.2     3.2     2.8     8.1
Evaporative Emissions     0.0     1.2     3.2     2.8     8.2
                       ------- ------- ------- ------- -------
Total % HC Reductions     0.0     3.7    10.2     9.0    25.2
```

Figure 5-2 Sample TDMLinK Output Report

5.3 TDMLinK Features

TDMLinK has been designed to be user friendly and help a transportation planner to estimate the impacts of different TDM strategies on emission impacts in simple and straight forward steps. TDMLinK does not require a person to be thoroughly knowledgeable about the working details of MOBILE5a. It guides the user through a series of steps to complete the process of estimation of emission reductions.

The user interface of MOBILE5a for interactive input is inadequate and is difficult to utilize. The input file preparation requires thorough knowledge of the sequence of input and FORTRAN specifications. The graphical user interface provided by TDMLinK eliminates the need for this knowledge. Also, the use of TDMLinK for the preparation of MOBILE input file and execution facilitates range checking on most of the input parameters specified, so that most of execution errors of MOBILE5a are eliminated. TDMLinK also checks if the input requirements as specified by the various control flags are completely satisfied. TDMLinK increases the efficiency of the process of estimation of emission reductions by providing the capability to do iterative analysis of various TDM strategies. Iterative analysis is performed by executing TDM and emission reduction process of TDMLinK sequentially.

5.3.1 TDMLinK Output Report

The output report produced by TDMLinK summarizes the whole process of estimation of emission reductions due to the implementation of various TDM strategies. As shown in Figure 5-2, information regarding the various files used in the estimation process is given. TDMLinK provides the summary information of percent emission reductions for each pollutant, for each TDM scenario, along with the summary information produced by TDM software. Inclusion of summary information from the

TDM output report facilitates the user to easily correlate the reduction in travel, to reduction in pollutant emissions. The total emissions calculated for each TDM scenario varies by the methodology used to estimate it. Thus, the emissions calculated by TDMLinK may be different from the emissions estimated by using another method. To resolve the ambiguity over the accuracy of the total emissions, TDMLinK provides the user with percentage emission reductions for every TDM scenario. The HC emission reductions are split into various components to give the user a better idea of how the TDM strategies are affecting the nature of the trips being made. For example, observing the reduction in cold start emissions, the planner would be able to recognize the effect of TDMs on the number of cold starts. This components of HC emission factors are printed only if the HC emission factors are modeled during the MOBILE5a execution. TDMLinK provides an opportunity for the user to save the output report as a file, and to print it, if desired.

5.4 Operating TDMLinK

TDMLinK is a menu driven software. Menus provide access to different input screens to supply various inputs required by TDMLinK. The inputs required by TDMLinK can be listed as follows:

1. TDM output report
2. MOBILE5a input parameters
3. Speed Elasticity
4. Cold Start Percentage
5. VMT Mix Composition Rates

The TDM output report and the MOBILE5a input parameters have to be specified for every TDMLinK run. Values to represent the local conditions of the area being

analyzed for all the three parameters can be specified for each run. However, default values of speed elasticity, cold/hot start percentages, and vehicle mix composition rates are provided in the software. The default values of cold start percentage and VMT mix composition rates represent the national average values.

5.4.1 TDM Output Report

To specify a TDM output report from the "File" menu, select "Open TDM File". TDMLinK then shows up a "File Open" dialog box. TDMLinK also shows this dialog box every time the program is started. This "File Open" dialog box can be used to locate the TDM output report in any drive/directory. The VMT and the total number of trips by each mode of transportation will be retrieved from the specified file. Since this information is available only with the output reports produced by versions 2.2 A or later of the TDM software, the output reports produced by earlier versions of the software would cause TDMLinK to produce the "File Format Unknown" error message.

5.4.2 MOBILE5a Input File

Two methods are available to access a MOBILE5a input file. By editing a new file using the graphical user interface provided by TDMLinK or, by opening a previously edited file, using TDMLinK or by any other text editor. New MOBILE5a input can be specified by selecting from the File menu \New MOBILE5a Input. To open a already edited file, select from the File menu \Open MOBILE5a File.

TDMLinK provides a limited application graphical user interface for developing MOBILE5a input files. MOBILE5a input has been divided into three sections: "Control", "One-Time" and "Scenario" data sections. The "Control" section screen

consists of all the flags required by MOBILE5a. The "One-Time" and "Scenario" data sections contain multiple screens. A separate screen is shown for each of the data records required in the "One-Time" and "Scenario" data sections. The number of data records required for a particular run depend upon the settings of the control flags in the "Control" section, thus the total number of input screens shown depend on the settings of the control flags.

5.4.2.1 Navigation

To maneuver through the different input screens for MOBILE5a, three buttons have been provided: "Next", "Back" and "GoTo". Also an "Exit" button is provided to end the input at any time. The buttons can be clicked using the mouse or by using the Keyboard combination of "ALT" + highlighted letter of the text on the button.

5.4.2.1.1 Next

If the user clicks on the "Next" button, TDMLinK compares the input values for different parameters to their respective allowable limits. If value(s) entered is(are) not within the allowable limits, a message box shows up informing the allowable values for the particular variable(s). If the input is within allowable limits, then the next logical input screen, depending upon the setting of control flags, is shown. The logical order of screens is defined by the order of input records placed in the MOBILE5a input file. Also, if the input is within the allowable limits, TDMLinK marks the particular data record to be full.

5.4.2.1.2 Back

If the user clicks on the "Back" button, TDMLinK does similar allowable limits check as clicking the "Next" button does. After checking the allowable limits, the next screen in the reverse order of data records is shown.

5.4.2.1.3 GoTo

The "GoTo" button allows the user to skip the normal sequential order of input screens and jump to the desired input record directly. Clicking "GoTo" button on any input screen shows up a dialog box as in Figure 5-3. If the screen from which the "GoTo" button is clicked is other than "Control" Section input screen, then a dialog box appears asking the user if he/she wishes to check whether the data entered for that particular screen is within the allowable limits or not. If the user chooses "Yes", then checking of the input values for the allowable limits is done. If the input values are within the allowable limits, then the "GoTo" screen is displayed; otherwise error(s) in the data will be displayed. If the user chooses "No", then the "GoTo" screen is directly displayed. As shown in Figure 5-3, "GoTo" screen consists of four buttons: "Control Section", "One-Time Section", "Scenario Section" and "Cancel"

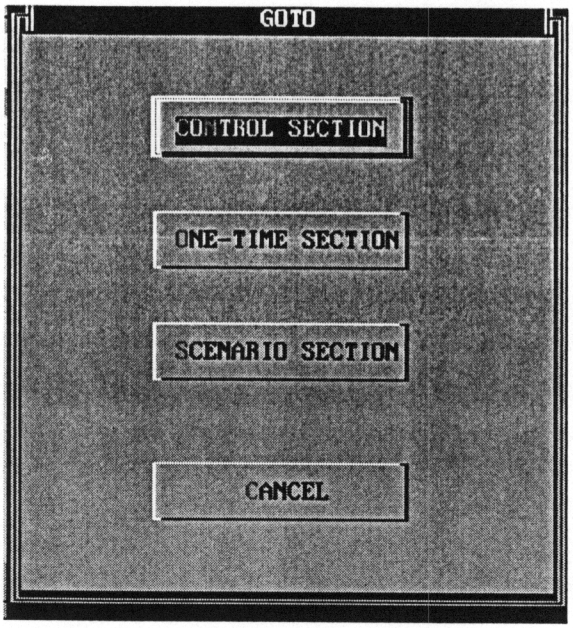


Figure 5-3 TDMLinK "GoTo" Screen

5.4.2.1.4 Control Section

Clicking on the "Control Section" button would take the user to "Control" Section flags input screen.

5.4.2.1.5 One-Time Section

Clicking on the "One-Time Section" would cause TDMLinK to display another screen with names of nine possible input screens of the "One-Time" data section listed. The text of the listing is dull or bright depending upon whether the input is required for that particular record, determined by the values specified in the control flag section. To the left side of the listings of the names, a flag indicates to the user if TDMLinK is expecting the user to provide the information for that particular record or not. If the flag indicates "FULL", required input has been provided for that record. If the flag indicates "NEED", then either input needs to be provided or it needs to be checked whether values are within the allowable limits or not for that particular record. To display a particular input record, the appropriate text should be selected and the "GoTo" button should be clicked. This would take the user to the appropriate input screen. If the user presses the "Cancel" button instead of "GoTo" button, the screen shown in Figure 5-3 will come up.

5.4.2.1.6 Scenario Section

Clicking the "Scenario" section on the "GoTo" Screen will display a small screen showing the names of two possible "Scenario" section input screens, namely, "Scenario Record" and "Additional Load Factors". Two flags to the left of the names of the records indicate if the input values for the particular record is required or not. Scenario record is mandatory for every MOBILE5a input.

5.4.2.1.7 Cancel

Clicking the "Cancel" button would result in closing the "GoTo" dialog box and the user will be return to the previous screen displayed.

5.4.2.2 Control Section

The screen shown in Figure 5-4 lists all the control flags required for the input sequence. A value can be specified for a control flag by typing it in the box besides the flag name. Help text on the allowable values and the description of what the value means for a flag is provided in the "Description" window when the cursor is placed in each flag box. The help text can be scrolled down and to the right using the scroll bars provided with the "Description" window. For some flags the values allowed in MOBILE5a have been restricted in TDMLinK. Most of the restrictions are imposed to ensue the development of MOBILE5a output file suitable for use by the TDMLinK software. Other flag values have been restricted due to the software development environment but can be overcome as explained in section 5.4.2.2.2 of this chapter. Flag restrictions are explained

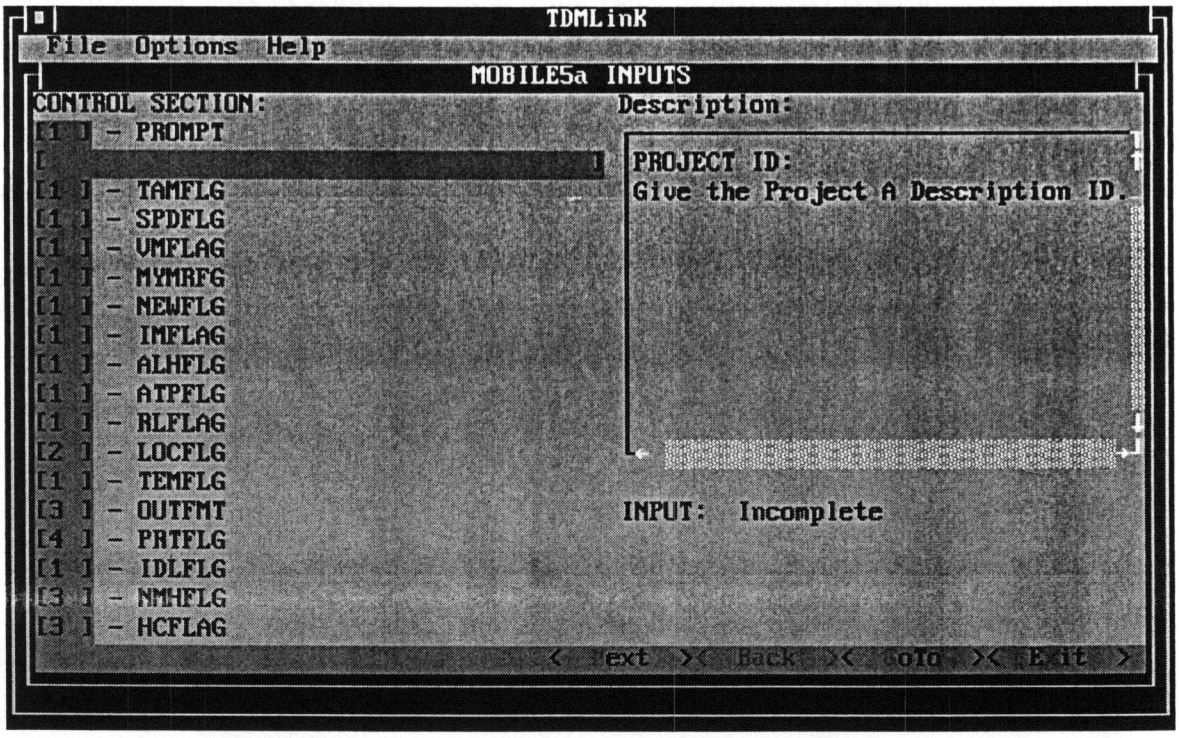


Figure 5-4 MOBILE5a Control Section Input Screen

in Section 5.4.2.2.1

The allowable flag values and the respective restrictions will be shown in the Description window when the cursor is placed in each respective text box as noted previously. TDMLinK does not allow the user to enter a value for a flag which is either out of range or is restricted for this application. When a MOBILE5a input file, developed by editing outside the TDMLinK environment, is opened, TDMLinK checks if all the flag values adhere to the allowable values in TDMLinK. If any of the flag value is outside the allowable limits then a message is displayed informing the user that an error occurred reading the input file and stops loading the file.

"Control" Section screen has a flag indicating if the MOBILE5a input is complete or not. This flag is updated whenever input for any of the data records is specified. This flag also acts like a checkpoint for MOBILE5a execution. If the flag indicates "Incomplete" then MOBILE5a execution is not allowed by TDMLinK.

5.4.2.2.1 Flag Restrictions

Flag values requiring the "Scenario" section input have been restricted for some of the control flags. As mentioned in section 5.2 only one base MOBILE5a scenario is allowed to be input by the user. Allowing the "Scenario" section input to this base scenario data would generate additional data without any effect on the output produced. This would result in the wastage of resources. Thus input of data in the one time data section was preferred to the scenario data.

The following are restrictions on some of the control flags in preparation of MOBILE5a input file using TDMLinK:

PROMPT: Only option 1 is allowed.

TAMFLG: In the interactive input mode only option 1 is allowed. However this limitation can be overcome as explained in Section 5.4.2.2.2.

SPDFLG: Option 1, to specify one value of speed in the scenario record is allowed. The value of speed for the base scenario is input by the user and the speed for other MOBILE scenarios is calculated by the software. Option 4 is allowed to specify the trip length distribution data for all the scenarios in the "One-Time" data section.

VMFLAG: Only option 1 is allowed. The VMT mix and the composite emission factors are calculated by the application, thus the input of the VMT mix is not required.

MYMRFG: Only option 1 is allowed. However this limitation can be overcome as explained in Section 5.4.2.2.2.

NEWFLG: Only option 1 is allowed. However this limitation can be overcome as explained in Section 5.4.2.2.2

LOCFLG: Local Area Parameter record is allowed only in the "One-Time" data section. This restriction is due to reasons explained above.

OUTFMT: Only output format 3 has been allowed. Component and total emission factors with detailed evaporative emission breakdown of the HC is required to calculate the reduction in evaporative emissions and exhaust emissions.

HCFLAG: Only option 3 is allowed for the reasons stated for flag OUTFMT.

5.4.2.2.2 Restrictions on TAMFLG, NEWFLG, MYMRFG

Restrictions in the development environment for the flags TAMFLG, NEWFLG, MYMRFG can be overcome by developing/editing the MOBILE input file outside

TDMLinK by using a text editor. A file developed outside with data records of any of these three flags, with appropriate flag settings, can be opened in TDMLinK. However the data for these records cannot be edited in TDMLinK. Also if the settings of such a control flag is changed in TDMLinK then the corresponding data records would be lost or the MOBILE5a input file may be saved incorrectly. Since TDMLinK user interface allows only "no-data" option for these control flags, changing the settings of these flags will cause the loss of data.

5.4.2.3 One-Time Data Section

The "Inspection and Maintenance" program screen shown in Figure 5-5 is next in the normal sequence of sequential input if the value of IMFLAG is set to 2, 3, 4 or 5. Up to two I/M programs can be defined. Typically these are used to specify two different I/M programs. The values for different variables can be specified by using the text boxes.

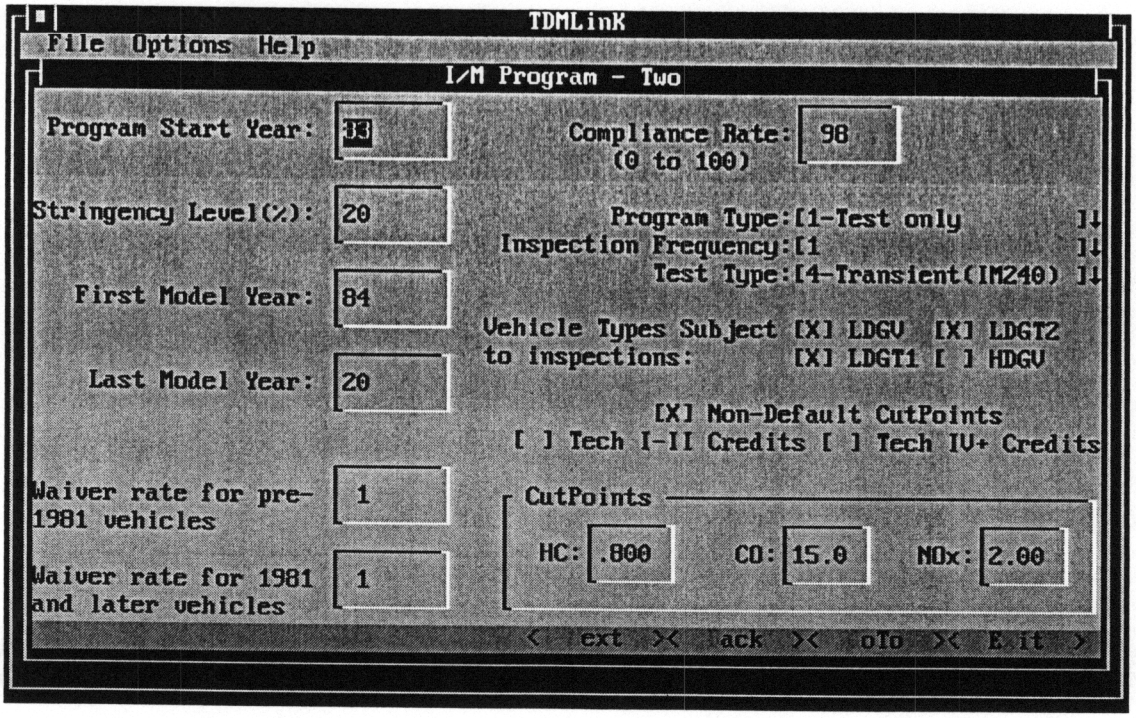


Figure 5-5 Inspection/Maintenance Program Input Screen

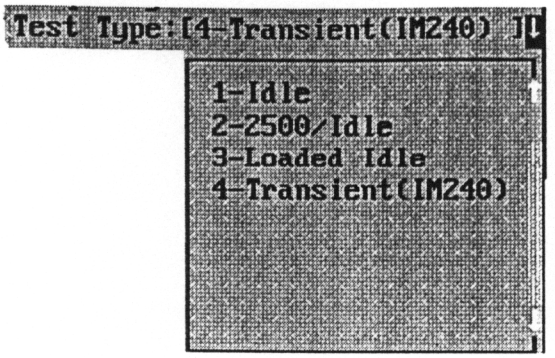


Figure 5-6 Drop Down Combo Box

A drop-down combo box as shown in Figure 5-6 has been provided for the variables: "Program Type", "Inspection Frequency" and "Test Type". Values for these variables can be specified by clicking on the arrow by the side of the box to display a list of choices available. Then click on the value of choice to make a selection. For the variables which effectively act as on/off switch, check boxes as shown in Figure 5-7 have been provided. To indicate that a variable is being modeled a check can be placed by clicking in the box by the side of the variable name. An empty box indicates that this variables is not being modeled.

Figure 5-7 Check Box

Input screens for the anti-tampering rates, functional pressure tests, and the functional purge tests are similar to each other. Helpful hints stating the upper and lower limits for each of the variable are given on each of these screens. Checking of the data entered in the input screens occurs every time the user moves through the screens using the "Next" or "Back" buttons.

The refueling emissions input screen shown in Figure 5-8 has two sections : "Stage II VRS" input record and "Onboard VRS" input record. Depending upon the value of the RLFLAG one of the two sections of the screen are made visible. If only

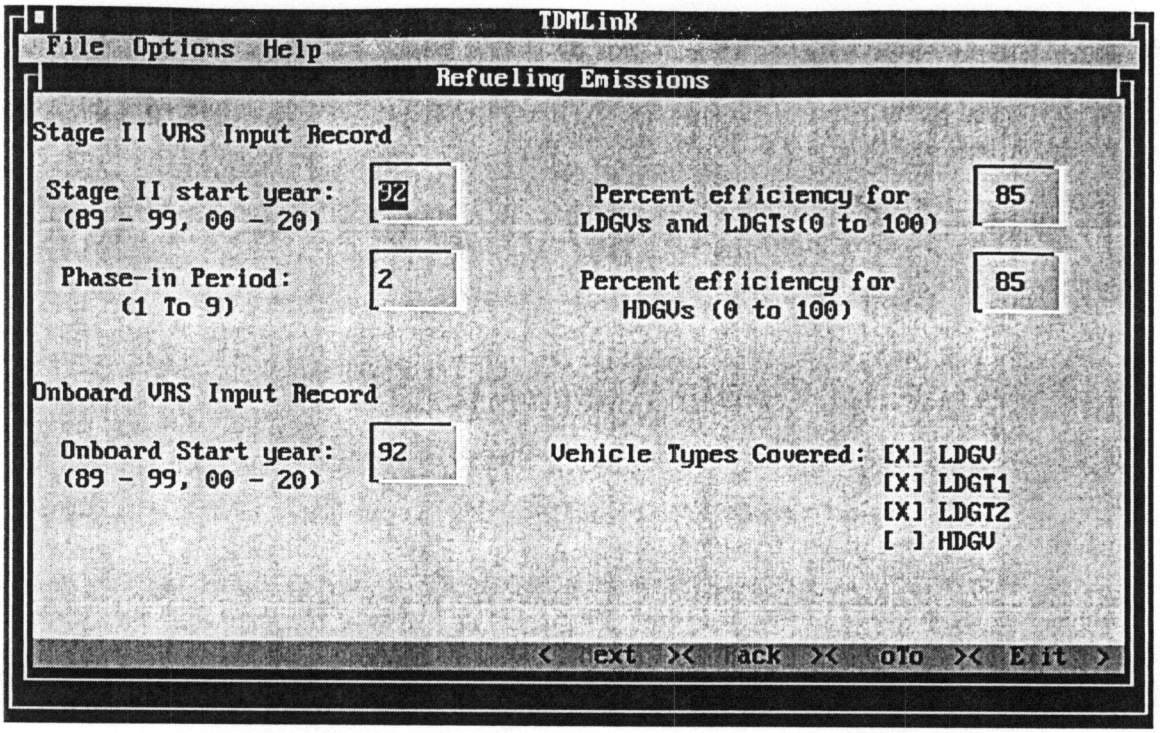


Figure 5-8 Refueling Emissions Input Record

"Stage II" input record is to be specified then the Onboard input record is not shown, and vice versa.

The "Local Area Parameter" record is specified in the "One-Time" data section. It is mandatory for every MOBILE5a run. Since the local area parameter record occurs in the "One-Time" data section, alternate light duty diesel vehicle and light duty diesel truck sales fraction cannot be supplied using the TDMLinK. Thus the value of diesel sales fraction setting for the local area parameter record must be specified as 1.

5.4.2.4 Scenario Data Section

The "Scenario Data Record" is mandatory for every run of MOBILE5a. Only one MOBILE5a scenario is required for each run of the TDMLinK. The "Scenario" record

input screen is shown in Figure 5-9. The user must provide input for five variables in the "Scenario" data record. If option 4 is specified for the variable "Region", then LEV

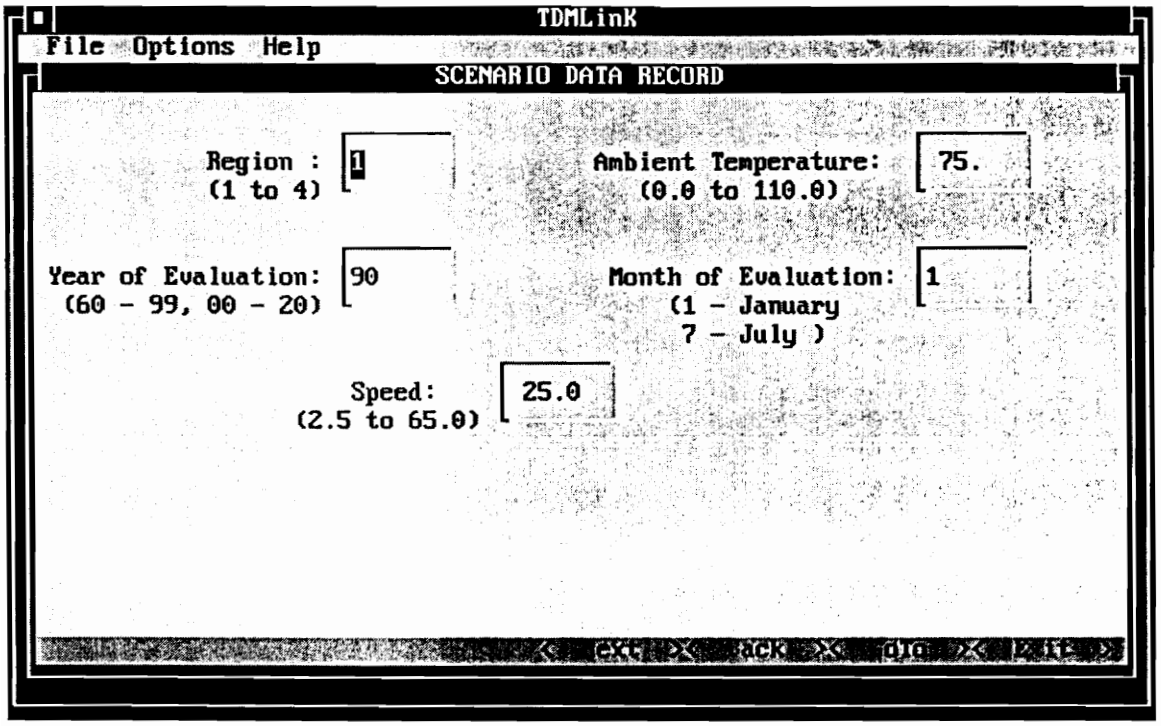


Figure 5-9 Scenario Data Record Screen

program parameters appear at the bottom of the Scenario data record. If the value of the region is changed from 4 to any other option then the LEV program parameters disappear.

Note: When a saved file is opened in TDMLinK, only the data from the first scenario record is read; all other scenario records are discarded.

TDMLinK allows the use of optional "Additional Correction Factors" record in the "Scenario" data section. The number of variables in the "Additional Correction Factors" record depend upon the setting of the flag ALHFLG. In the "Scenario" data section the "Next" button is replaced with a "Check" button if there are no more input

screens in the logical order of input. Clicking on the "Check" button would check the data entered on the screen is within the allowable limits and would report if any invalid data is entered.

5.4.3 Options Menu

The "Options" Menu, shown in Figure 5-10, can be used to access travel parameter settings used by TDMLinK, in the calculation of the emission factors. If the user changes the values of these parameters, then altered values will be used only for the current TDMLinK session. Therefore if the user runs the TDMLinK in a iterative process with TDM software the values must be changed after each TDM session. Selecting

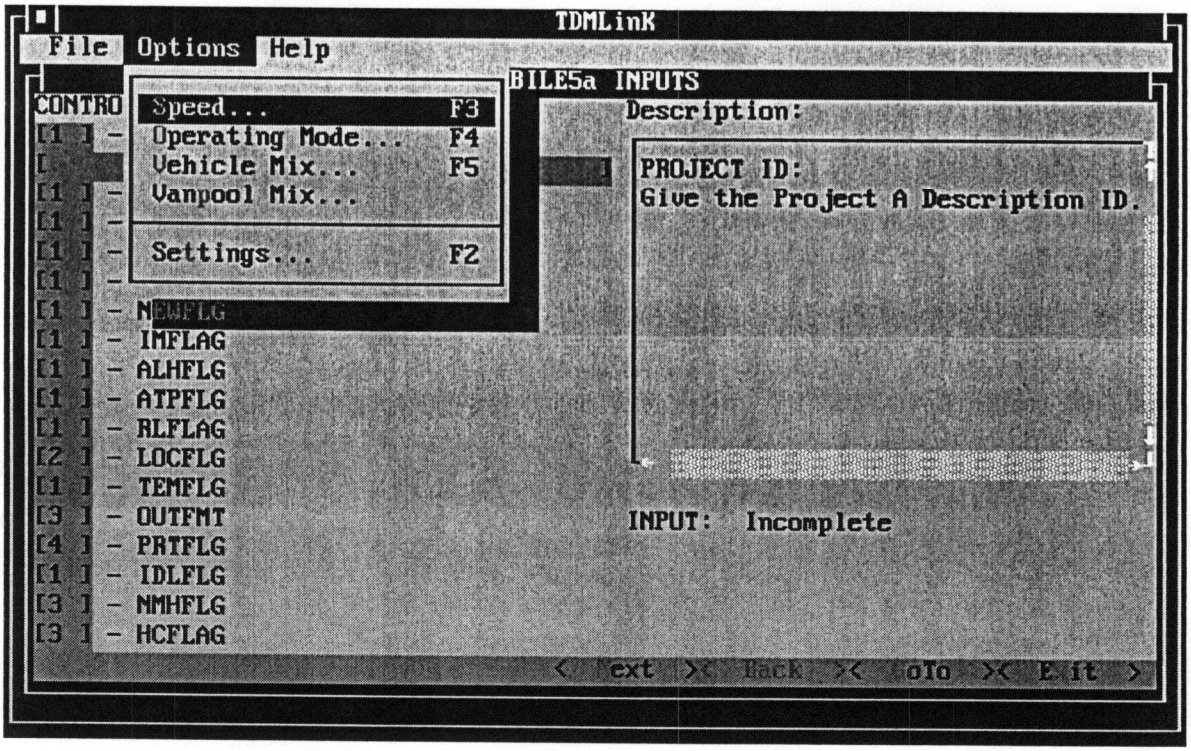


Figure 5-10 Options Menu

"Settings" command from the "Options" menu allows the user to change paths of the TDM and MOBILE5a executable files. A default directory for MOBILE5a output files can also be specified from this screen.

The "Speed" menu allows the user to change the value of elasticity of speed with respect to volume. This value will be used in the estimation of speed for various TDM scenarios. "Operating Mode" menu will allow the user to specify a different value for the percent of home-based work trips starting cold for the morning peak hour. This value will be used in the estimation of number of trips starting cold. The "Vehicle Mix" and "Vanpool Mix" menus allows the user to specify vehicle composition rates, which are used in the estimation of the VMT mix for each TDM scenario.

5.5 TDMLinK Test Runs

To evaluate the proper functioning of TDMLinK some test runs were made using hypothetical data. A hypothetical network of 19 zones was used to evaluate the TDM scenarios. The TDM strategies applied ranged from employer supported programs to area wide implemented programs. These strategies were executed using version 2.2A of TDM software. Four TDM scenarios consisting of various TDM strategies were evaluated. This section describes the details of the network, the TDM scenarios evaluated, the results obtained from TDM software, execution of TDMLinK, the MOBILE5a input file, and the results obtained by TDMLinK.

5.5.1 Network

The hypothetical network consisted of 19 zones. Trip tables in the MINUTP format were used as the input to the TDM software. Person trip table, vehicle trip table,

transit trip table, and distance trip tables in MINUTP format were specified as input to the TDM software. The person trip table provided the details about the person trips across the network. Similarly, vehicle trip tables and transit trip tables provided the information about the vehicle and transit trips across the network. The distance trip table was used as skim matrix, giving the distance between each zones, which is used to calculate the VMT traveled for each trip. TDM software also accepts a vanpool trip table as an optional input. A vanpool trip table was not specified for the test runs.

5.5.2 Base Scenario

The network originally consisted of 7176 person trips, 6240 vehicle trips, with a total VMT of 8552. The drive alone rate or SOV rate was 77.1%. Similarly, the transit, carpool, and the vanpool rates were 2.4 %, 20.6 % and 0.0 % respectively. The average vehicle occupancy rate was 1.15. It was assumed that there was an existing employer supported carpool and transit programs in place. The level of these efforts was assumed to be minimum.

5.5.3 Scenario One

The first scenario consisted of employer supported carpool program, with incentives provided by employers in the form preferential parking and reduced parking costs for ridesharing. Some areawide TDM strategies, such as transit improvements and HOV lane time savings were also considered. The employer supported carpool program increased the current level of effort from 1 to 3. The participation rate of the employers was assumed to be at level 2, which meant that the participation of an employer in the program was voluntary and there was no legal requirement compelling the employer to participate in the program. Employer incentive program in the form of preferential

parking and reduced parking costs were evaluated. A two minute increase in the walk time and an increase of $1.00 in the parking costs were assessed for SOVs. For HOV2, walk time was the same as original, but a reduction of $ 1.00 in parking cost was assessed. Similarly, for HOV3, there was one minute reduction in walk time and $ 2.00 reduction in parking costs; for HOV4+, a reduction of two minute walk time and $ 1.50 in parking costs, and for vanpool, a reduction of three minute walk time and $ 12.00 in parking costs were assessed. The participation rate of the employers was set to level two, meaning the participation of the employers in this program was voluntary and no legal requirement was in place. The areawide programs consisted of transit improvements in the form of reduction in In-Vehicle Time (IVT) and Out-of-Vehicle Time (OVT), and HOV lane time savings. A reduction of 5 minutes of both IVT and OVT was assumed due to the transit improvements. A time saving of 2.5 minutes was assumed for a HOV2 lane implementation. Also, an areawide parking incentive in the form of savings of $ 2.00 for a HOV4+ was evaluated.

5.5.4 Scenario Two

Scenario two consisted of TDMs similar to that of scenario one. The employer supported TDM measure was changed from a carpool measure to a vanpool measure. The level of effort for the vanpool program was increased to 2, meaning an in-house vanpool matching program with a quarter time transportation coordinator, and no monetary incentive was being implemented. The participation rate of the employers was set to three, meaning that there is a legal requirement for any new employer entering the area to participate in the program. The employer incentive program for preferential parking was similar to the that of scenario one. The areawide TDMs for scenario one were adopted for scenario two also.

5.5.5 Scenario Three

Similar to scenario two, the employer supported program was changed to a transit program. Transit program at a level of 3 was implemented. Level 3 effort meant that there was a transit information center, with policy of flex hours, on-site bus pass sales and the availability of a half-time transportation coordinator. The participation rate of employers was set to four, meaning that the program participation was mandatory for all the employers in the area. The employer incentives for preferential parking were same as for scenario one and scenario two. The areawide TDMs implemented were same as for the previous scenario.

5.5.6 Scenario Four

The employer supported programs in scenario four were developed as a combination of the employer supported measures implemented in scenarios one, two, and three. Thus, the scenario four employer supported program consisted of carpool program with level of effort at 3 and participation rate of 2, a vanpool program with level of effort at 2 and participation rate of 3, and a transit program with level of effort at 3 and participation rate of four. The employer incentive program for preferential parking was not changed from that of previous scenarios. Similarly, the areawide TDMs were the same as previous scenarios.

5.5.7 TDM Results

After the entry of specifications of TDM scenarios, the scenarios were evaluated and the resulting trip tables were obtained. TDM software also output the VMT, person trips, vehicle trips and mode share for each of the TDM scenario evaluated. Also, percent

reduction of person trips, vehicle trips and VMT is given in the summary information. Part of the output report produced by TDM software is shown in Figure 5-11. It shows summary results with percent reductions for each TDM scenario modeled.

Implementation of the carpool program with other employer incentive and areawide TDM measures in scenario one resulted in a reduction of 4.4 percent of vehicle trips and a similar amount of VMT. The resulting vehicle trips and VMT were 6240 and 8172 respectively. There was no change in the number of person trips due to the implementation of TDM measures. In scenario two, implementation of vanpool program resulted in a reduction of 4.6 % of VMT and vehicle trips. In scenario three, the implementation of transit program in addition to the measures common to all the scenarios resulted in a reduction of 5.5 % of vehicle trips and 5.6 % of VMT. In the fourth scenario, which was a combination of the first three scenarios, a total reduction of 6.6 % of VMT and vehicle trips were seen. In addition to this output, TDM provided reduction in VMT and vehicle trips by each mode of transportation for every scenario.

5.5.8 TDMLinK Execution

At the end of execution of TDM software, execution of TDMLinK was initiated. The output report produced by TDM software was used as input to the TDMLinK software, to provide the information on reduction of VMT, vehicle trips for each mode of transportation and the TDM scenarios. A MOBILE5a input file was prepared using the user interface provided by TDMLinK.

*** Summary Report *** SAMPLE.RPT 14 Dec 19

Sample Scenario

	PERCENT MODE SHARE					PEAK HOUR			% REDUCTION		
	DA	TRN	CP	VP	AVR	PERSON TRIPS	VEHICLE TRIPS	V M T	PERS TRIPS	VEH TRIPS	VMT
0	77.1	2.4	20.6	.0	1.15	7176	6240	8552			
1	70.5	3.2	26.3	.0	1.20	7176	5963	8172	.0	4.4	4.4
2	70.8	3.2	25.4	.6	1.21	7176	5954	8156	.0	4.6	4.6
3	70.1	4.8	25.1	.0	1.22	7176	5894	8073	.0	5.5	5.6
4	69.0	4.7	25.7	.6	1.23	7176	5831	7990	.0	6.6	6.6

Scenario Descriptions

0 Base Conditions
1 Trial 1
2 Trial 2
3 Trial 3
4 Trial 4

Trip and VMT Changes (Trial vs. Base)

		Base	Trial 1	Trial 2	Trial 3	Trial 4
SOV	Vehicles	5529	5060	5080	5029	4948
	VMT	7603	6962	6989	6918	6808
	% change	---	-8.4	-8.1	-9.0	-10.5
HOV 2	Vehicles	678	860	830	822	841
	VMT	910	1157	1116	1104	1131
	% change	---	27.1	22.6	21.3	24.3
HOV 3	Vehicles	23	29	28	27	28
	VMT	28	35	34	33	34
	% change	---	26.1	22.0	20.8	23.3
HOV 4+	Vehicles	10	16	15	15	15
	VMT	11	18	17	17	17
	% change	---	58.6	53.8	52.3	55.1
Vanpool	Vehicles	0	0	4	0	4
	VMT	0	0	5	0	5
	% change	---	.0	.0	.0	.0
Total Auto	Vehicles	6240	5965	5953	5893	5832
	VMT	8552	8172	8156	8074	7990
	% change	---	-4.4	-4.6	-5.6	-6.6

Figure 5-11 TDM Output of Summary Results

5.5.9 MOBILE5a Input

Emission factors were modeled for implementation of anti-tampering program, functional pressure check and functional purge check programs. The default rates provided in MOBILE5a were used for tampering rates, mileage accumulation and registration distribution rates. The control flag for speed was set to 1, indicating that only one value of speed will be provided in the scenario record. The control flag for VMT mix was set to one, indicating that the default rates of VMT mix will be used by MOBILE5a. However, setting of this flag is independent to the estimation of emissions by TDMLinK. TDMLinK uses the VMT mix estimated by itself to calculate the emissions for each TDM scenario. NEWFLG flag was set to 1, to use the basic emission rates provided by MOBILE5a. The value of IMFLAG was set to 1, indicating that there were no inspection / maintenance programs being implemented. No Additional load factors and refueling emission factors were included in the development of the MOBILE5a input file. The local area parameter record flag was set to 2 implying that only one local area parameter record will be provided in the "One-Time" data section. The output format control flag was set to 3, so that MOBILE5a outputs the emission factor components of HC. PRTFLG was set to 4, indicating emission factors to be calculated for all the three pollutants. Idling emission factors were not modeled. The NMHFLG flag was set to 3, to indicate that the volatile organic compounds (VOC) be modeled. The HCFLAG was set to 3 to indicate that component and total emission factors be printed out with detailed break down of evaporative emission factors.

An anti-tampering rate program starting in 1983 with a annual frequency and a compliance rate of 98 % was modeled. This anti-tampering program affected the LDGV, LDGT1 and LDGT2 vehicles. Various types of inspections were modeled. This program was assumed to be implemented on vehicles with model years from 1975 to 2020. A functional pressure test program was modeled for model year vehicles ranging from 1971

to 2020 starting in the year 1990, with an annual frequency and 98.0 % compliance rate. A functional purge test was also modeled for model year vehicles ranging from 1984 to 2020, with similar characteristics to that of functional pressure check program. These programs affected the vehicles belonging to the LDGV, LDGT1 and LDGT2 classes. The local area parameter record specified a minimum and maximum temperature of 72.0 and 92.0° F respectively.

Only one MOBILE5a scenario record was specified using the user interface of TDMLinK. The scenario record specified that the area being modeled is a low altitude area with an ambient temperature of 75.0 ° F. The year of evaluation was set to 2000. The month of evaluation was set to January. Initial speed of 19.6 mph was specified for the base TDM scenario on the scenario record.

Default value of elasticity of speed with respect to volume, -0.750, was used in the estimation of speed for various TDM scenarios. After specifying all the required MOBILE5a input data, MOBILE5a was executed and an output report was produced. Part of this output is shown in Figure 5-12. This output shows the detailed breakdown of emission factors for three pollutants and also the component breakdown of evaporative emission factors. These emission factors are produced for MOBILE5a scenario one, with 100 % cold start VMT and a base scenario speed of 19.6 mph.

Emission factors from this file and default values of vehicle composition rates and percent morning peak home-based work trips starting cold, provided in the TDMLinK, were used in the estimation of reduction of emissions. At the end of calculation process an output report was produced by TDMLinK.

```
1  Demonstration of ATP 8 - user specifies an ATP and purge and pressure checks.
 MOBILE5a (26-Mar-93)
0
-M114 Warning:
+             Purge Check emission benefits assume the use of a dynomometer and
              the IM240 transient test procedure driving cycle.
0Functional Check Program Description:
0Check Start   Model Yrs  Vehicle Classes Covered       Inspection       Comp
      (Jan1)  Covered    LDGV   LDGT1  LDGT2  HDGV    Type      Freq     Rate

 Press 1990    1971-2020 Yes    Yes    Yes    No  Test Only     Annual    98.0%
 Purge 1990    1984-2020 Yes    Yes    Yes    No  Test Only     Annual    98.0%
 ATP   1983    1975-2020 Yes    Yes    Yes    No  Test Only     Annual    98.0%
0Air pump system disablements:       Yes  Catalyst removals:                 Yes
 Fuel inlet restrictor disablements: Yes  Tailpipe lead deposit test:         Yes
 EGR disablement:                    No   Evaporative system disablements:   Yes
 PCV system disablements:            Yes  Missing gas caps:                  Yes
0Scenario title.                          Minimum Temp:  72. (F)        Maximum Temp:  92. (F)
                    Period 1 RVP: 11.5    Period 2 RVP:  8.7       Period 2 Start Yr: 1992
0VOC HC emission factors include all evaporative HC emission factors, except for refueling emissions.
0_____________________________________________________________________________________________
0Emission factors are as of Jan. 1st of the indicated calendar year.
0Cal. Year: 2000        I/M Program: No        Ambient Temp: 87.5 / 87.5 / 87.5 (F) Region: Low
                Anti-tam. Program: Yes     Operating Mode:100.0 /  0.0 /100.0   Altitude:  500. Ft.
                 Reformulated Gas: No
0  Veh. Type:     LDGV     LDGT1     LDGT2      LDGT      HDGV      LDDV      LDDT      HDDV      MC      All Veh
+
 Veh. Speeds:    19.6      19.6      19.6                 19.6      19.6      19.6      19.6      19.6
     VMT Mix:    0.616     0.191     0.086                0.031     0.002     0.001     0.068     0.006
0Composite Emission Factors (Gm/Mile)
 VOC      HC:    3.19      3.39      4.51      3.73       6.72      0.88      1.30      2.23      6.28      3.400
 Exhaust  HC:    2.68      2.95      3.94      3.26       3.24      0.88      1.30      2.23      2.64      2.824
 Evaporat HC:    0.16      0.20      0.25      0.21       2.32                                    3.21      0.248
 Refuel L HC:    0.19      0.25      0.25      0.25       0.41                                              0.196
 Runing L HC:    0.29      0.17      0.25      0.20       1.05                                              0.266
 Rsting L HC:    0.06      0.06      0.06      0.06       0.10                                    0.43      0.062
 Exhaust  CO:   34.35     39.50     51.72     43.30      66.26      2.79      2.88     11.58     27.94     36.146
 Exhaust NOX:    1.67      1.99      2.70      2.21       4.82      1.39      1.74     10.69      0.82      2.525
0Evaporative Emissions by Component                  Weathered RVP:  8.3          Hot Soak Temp: 88.6 (F)
 (Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr)   Running Loss Temp: 89.2 (F)
                                                                                  Resting Loss Temp: 82.5 (F)
 Hot Soak        0.81      1.02      1.40      1.13       9.22                                    13.51
 WtDiurnal       1.23      1.97      3.49      2.41      23.85                                    13.90
 Multiple        6.57      7.92      9.25      8.31      33.39
 Crankcase       0.00      0.00      0.00      0.00       0.02                                    0.00
 Refuel          4.19      4.19      4.19      4.19       4.19
 Resting         0.07      0.07      0.08      0.08       0.11                                    0.18
```

Figure 5-12 MOBILE5a Scenario One Output

5.5.10 Results of TDMLinK

The output report produced by TDMLinK is shown in Figure 5-13. The results shows the percent reductions in emissions in comparison to the percent reduction in VMT

and vehicle trips obtained by TDM software. For the TDM scenario one, a reduction of 6.8 %, 7.9 %, and 4.1 % were obtained for HC, CO and NOx respectively. These reductions were as a result of a reduction of 4.4 % in VMT and vehicle trips. Similar reductions were seen for other three scenarios as shown in Figure 5-13.

TDMLinK OUTPUT REPORT

Sample Scenario

TDM OUTPUT FILE : T:\TEMP\PRASHANT\DOCS\TDM\SAMPLE.RPT
MOBILE5A INPUT FILE : T:\TEMP\PRASHANT\DOCS\M5A\INOUT\ATP8.IN
MOBILE5A OUTPUT FILE : T:\TEMP\PRASHANT\DOCS\M5A\INOUT\ATP8.OUT
TDMLinK REPORT : T:\TEMP\PRASHANT\DOCS\TDMLINK\SAMPL.TMO

	PERCENT MODE SHARE				P E A K H O U R		
	DA	TRN	CP	VP	PERSON TRIPS	VEHICLE TRIPS	V M T
0	77.1	2.4	20.6	.0	7176	6240	8552
1	70.5	3.2	26.3	.0	7176	5963	8172
2	70.8	3.2	25.4	.6	7176	5954	8156
3	70.1	4.8	25.1	.0	7176	5894	8073
4	69.0	4.7	25.7	.6	7176	5831	7990

% REDUCTION IN TRAVEL AND EMISSIONS

	TRAVEL			EMISSIONS		
	PERS TRIPS	VEH TRIPS	VMT	TOTAL HC	CO	NOx
0						
1	.0	4.4	4.4	6.8	7.9	4.1
2	.0	4.6	4.6	6.9	8.0	4.2
3	.0	5.5	5.6	8.3	9.5	5.3
4	.0	6.6	6.6	10.1	11.2	5.3

HC EMISSION COMPONENTS % REDUCTION

	Base	Trial 1	Trial 2	Trial 3	Trial 4
Cold Start Emissions	0.0	3.6	3.6	4.3	5.4
Running Emissions	0.0	2.1	2.1	2.6	3.1
Evaporative Emissions	0.0	1.1	1.1	1.4	1.6
Total % HC Reductions	0.0	6.8	6.9	8.3	10.1

Figure 5-13 TDMLinK Output Report

The results obtained were predictable, showing a direct relationship between the number of trips and VMT reduced, and the overall percent emissions reduced. The component division of HC emissions reductions showed that the cold start emissions reductions are directly related to the reductions in number of trips. However, these findings have to be further investigated for definitive conclusions. Also, the test runs performed do not indicate specific change in emission reduction behavior with respect to change in the values of three parameters speed, VMT mix and operating mode mix, studied in this research. Sensitivity analysis needs to be performed to determine their effect on emission reductions. This will be valuable in evaluating the methodologies incorporated into TDMLinK.

6. SUMMARY

Emission impacts of Transportation Control Measures (TCM) have taken increased significance for the purpose of inclusion into the State Implementation Plans (SIP), after the passage of Clean Air Act Amendments (CAAA) of 1990. Various tools are currently employed to evaluate the emission impacts of the TCMs. The tool employed is dependent on the level of analysis required to be performed, the TCM being evaluated, and applicability of the methodology used in the tool to the area of study. Travel Demand Management (TDM) software is a widely used tool to evaluate TDM strategies for their transportation impacts. Use of TDM software for emission impact analysis and screening of TDMs is a labor intensive and time consuming process. Also, the impact of TDMs using the TDM software in the traditional procedure does not take into account some of the changes in travel parameters such as VMT mix and operating mode mix, which can significantly affect the emission factors estimated by MOBILE5a.

In this research work, a software model was developed linking TDM software and an emission factor model to ease the process of estimation of emission impacts of TDM strategies. MOBILE5a developed by EPA was used as the emission factor model. Consideration of influence of three travel parameters, namely, speed, operating mode mix and VMT mix, on emission factors were deemed important for an effective linkage between the TDM software and an emission factor model. Methodologies were formulated to predict the changes in the values of speed and operating mode mix using the Sierra methodology. To estimate the change in the VMT mix, vehicle composition rates were developed. These rates were developed by analyzing the NPTS data for the relationship between vehicle used on a trip and the number of occupants in the vehicle. These vehicle composition rates were used in the calculation of the VMT mix rates for every TDM scenario evaluated.

The results of NPTS analysis for vehicle composition rates provided a good

insight on the vehicle usage with the increase in the vehicle occupancy. The single occupancy vehicles (SOVs) had a significant share of VMT accumulated by Light Duty Gasoline Vehicles (LDGV). The share of LDGV vehicles increased slightly when the vehicle occupancy increased from SOV to carpool. There was a corresponding change in the percent Light Duty Gasoline Truck (LDGT) vehicles. However, there was a significant change in the percent of VMT accumulated by LDGV and LDGT vehicles for vanpools. Slight difference between the percent of VMT accumulated by LDGV and LDGT vehicles for SOV and carpool modes meant that vehicle usage behavior does not change to a large extent for a TDM measure promoting carpool measures. Hence, there will not be a major change in the emissions with respect to VMT mix. However, if a TDM measure results in more vanpool usage, then there will be a significant shift in the vehicle miles accumulated from LDGV to LDGT vehicles. Since the LDGT vehicles have higher emission factors relative to LDGV vehicles, the TDM measure may result in higher emission factors, when everything else remains the same.

A software model named TDMLinK was developed linking the TDM software and MOBILE5a. TDMLinK incorporates the methodologies formulated to predict the changes in the values of speed, operating mode mix and VMT mix. Using TDMLinK, sample test case was run to evaluate its effectiveness. The results of the test case showed that the reduction of emissions were directly related to the reduction in travel parameters: VMT, and vehicle trips. TDMLinK eases the screening process of TDMs to be included into a transportation program or plan. It extends the ability of TDM software to perform emission impact analysis of TDM software. The graphical user interface of TDMLinK for the preparation of a MOBILE input file simplifies the process of TDM evaluation for a transportation planner and does not require in-depth working knowledge of MOBILE5a.

6.1 RECOMMENDATIONS

The NPTS data had severe limitations with regard to the classification of the

vehicles for non-household data. The classification of light duty truck data was weighted by the registration/production data provided by the vehicle manufacturers. A data source which compiles the data on vehicle make, series and model of the vehicle used, on a trip along with trip purpose and vehicle occupancy is desirable.

The vehicle composition rates developed using the 1990 NPTS corresponded to 1990 vehicle usage characteristics. Over a period of time the vehicle usage characteristics tend to change. This was best exemplified by the increase in the usage of light duty trucks over light duty vehicles in 1980's when compared to 1970's. Thus, a mechanism needs to be developed to forecast 1990 data to reflect current year trends in the vehicle usage.

MOBILE5a estimates the emission factors for Heavy Duty Diesel Vehicles (HDDV). These emission factors include those of the urban transit buses. However, the emission characteristics of the urban transit buses are different from other heavy duty vehicles, since they operate differently. Also, the effect of TDM policies on urban transit buses is different from to that of other heavy duty vehicles. Thus, a method is needed to determine the gram/mile emission rates of transit buses.

A region being subjected to the travel demand management strategies may consist of different sub fleet of vehicles subjected to different levels of Inspection / Maintenance programs. Thus, the emission characteristics of different fleets would vary. Adding the capabilities of performing subfleet analysis and combining the results to depict that of a region would enhance the applicability of the software to a wide array of areas. Finally, thorough software testing needs to be carried out. A case study may be performed to validate the methodology used by TDMLinK in estimating the emission reductions.

REFERENCES

1. Shrouds, J. M., "Transportation Planning Requirements of the Federal Clean Air Act Amendments (CAAAs) of 1990": A Highway Perspective", Federal Highway Administration, Washington, D.C.

2. Hawthorn, G., "Transportation Provisions in the Clean Air Act Amendments of 1990", ITE Journal, Institute of Transportation Engineers, April 1991

3. Volpe National Transportation Research Center, *Evaluation of MOBILE Vehicle Emission Model,* developed for Federal Highway Administration, FHWA, Washington, D.C. December 1994.

4. Suhrbier, J. H., Lawton, S. T., and Moriarty, J. A., "Preparation of Highway Vehicle Emission Inventories", Transportation Research Record 1312, pp 42-49

5. COMSIS, Federal Transit Administration, *User's Guide to Travel Demand Management Evaluation Model,* developed for Federal Highway Administration, Washington, D.C., June 1993.

6. COMSIS Corporation, *Evaluation of Transportation Control Measures For Philadelphia Region 15% Emissions Reduction SIP*, developed for Delaware Valley Regional Planning Commission, Silver Spring, MD, February 1994

7. Environmental Protection Agency, *User's Guide to MOBILE5 (Mobile Source Emission Factor Model)*, Ann Arbor, Michigan, May 1994.

8. Sierra Research, Inc., *User Manual for Software Developed to Quantify the Emission Reductions and Cost Effectiveness of Selected Transportation Control Measures,* developed for Federal Highway Administration, Sacramento, California, July 1994

9. Kierr, Tom, Sierra Research Inc., Conversation about Houston-Galveston research on elasticity on speed, October, 1995

10. Correspondence between Mr. Robert G. Dulla, Sierra Research, and Mr. Philip Lorang, U.S. Environmental Protection Agency, about Sierra Methodology, February 1993.

11. Texas Transportation Institute, *TCM Analyst 1.0 and User's Guide*, developed for Texas Dept. of Transportation, Research Report 1279-7, College Station, Texas, November 1994

12. Systems Applications International, *Methodologies for Estimating Emission and Travel Activity Effects of TCMs,* developed for Environmental Protection Agency, July 1994.

13. JHK & Associates, with Sierra Research, Inc. and Project Technical Working Group, *San Joaquin Valley Transportation Control Measure Program*, January 1994

14. Venigalla M., M., *A Network Assignment Based Approach to Modeling Mobile Source Emissions,* Dissertation for the Doctor of Philosophy Degree, Knoxville, Tennessee, May 1994

15. Venigalla M., M., Miller, T., Chatterjee, A., "Start Modes of Trips for Mobile Source Emissions Modeling", 74th Annual Meeting, Transportation Research Board, Washington D.C., January 1995

16. Venigalla M., M., Miller, T, Chatterjee, A., "Alternative Operating Mode Fractions to the F.T.P. Mode Mix for Mobile Source Emissions Modeling", 74th Annual Meeting, Transportation Research Board, Washington D.C., January 1995

17. Research Triangle Institute, *User's Guide For the Public Use Tapes, 1990 Nationwide Personal Transportation Survey,* developed for Federal Highway, Administration FHWA, Washington, D.C., December 1991

18. SAS Institute Inc., *SAS User's Guide: Basics* Version 5 Edition, Cary, North Carolina, 1986.

19. User Services, Virginia Tech Computing Center, *Using the SAS System*, July 1993.

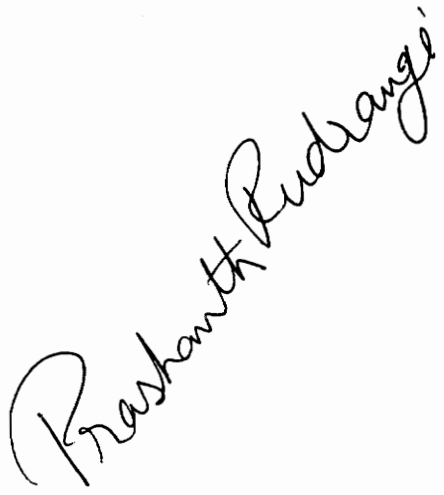
20. Ward's , *Ward's Automotive Yearbook,* 1965 - 1993

21. Jefferson, Mitchell, *Chevrolet Truck Data,* Chevrolet Truck Division, December 1995

22. Reuter, Dave, *Ford Truck Data,* Ford Brand Communications, January 1996

23. Schwartz, Molly, *Chrysler Truck Data,* Chrysler Motors Corporation, November 1995

24. McDonald, Dough, VPSI Commuter Vanpool. Data regarding Vehicles used by vanpools.

VITA

Prashanth Rudrangi was born on 1st of March 1973, in the southern Indian city of Hyderabad. His entire education career, through his undergraduate degree, was spent in Hyderabad. He pursued Civil Engineering undergraduate degree in Osmania University. He was ranked 1 in a class of 60 students at the completion of his B.E. With the emotional and financial support of his family he enrolled for a Master of Science program in the Civil Engineering Department of Virginia Tech in Fall of 1994. His concentration of study for the Master's program was Transportation Engineering. At the end of two semesters of course work at Virginia Tech, he was endowed with Dwight D. Eisenhower Grants For Research Fellowship by National Highway Institute. As part of the fellowship program he successfully performed research work for Federal Highway Administration for one year. At the end of the fellowship period he successfully defended his Master's degree. He currently gainfully employed at USF&G Company in the city of Baltimore, MD.