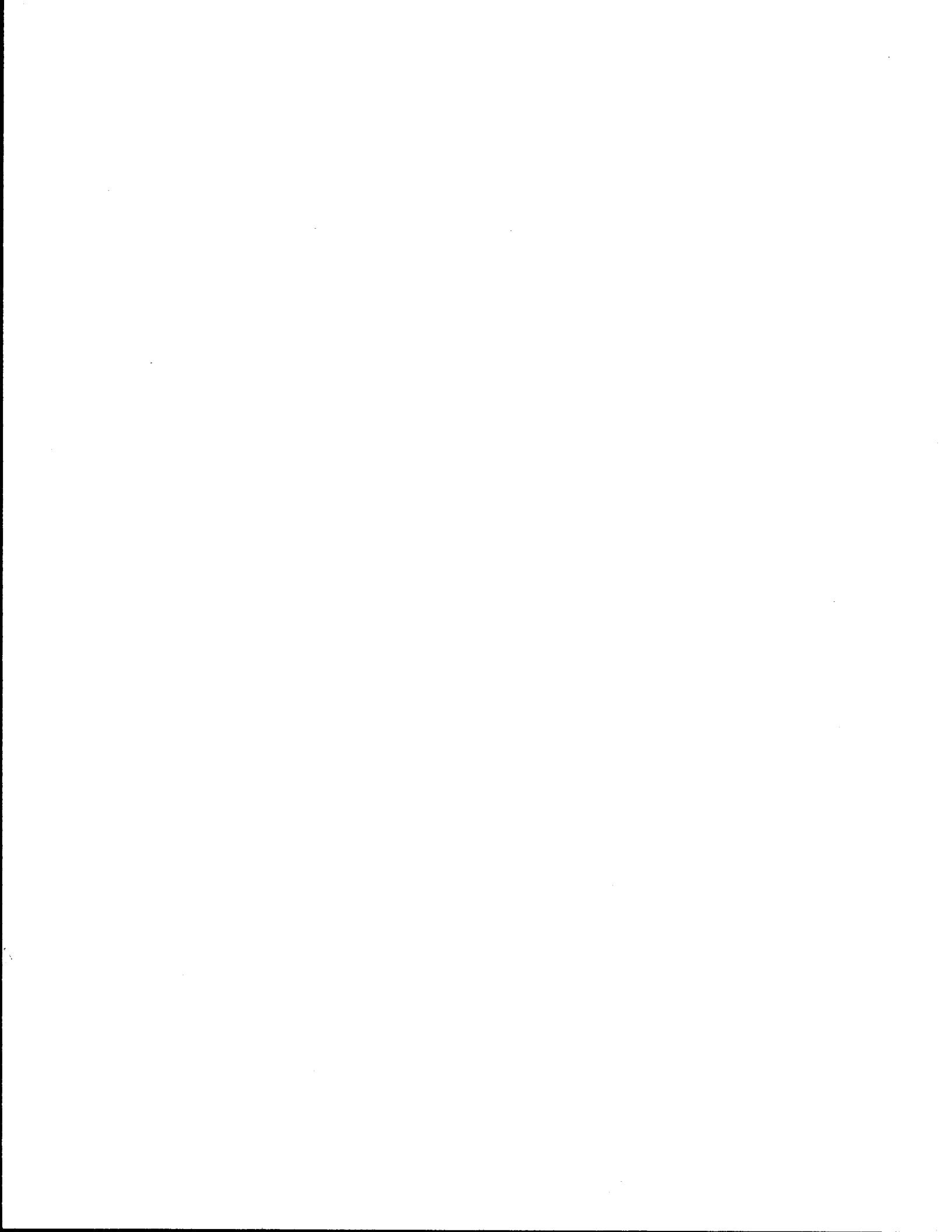


1. Report No. FHWA/TX-94/1353-2		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle MOBILE SOURCE EMISSION IMPACTS OF HIGH OCCUPANCY VEHICLE FACILITIES				5. Report Date November 1994	
				6. Performing Organization Code	
7. Author(s) William E. Knowles				8. Performing Organization Report No. Research Report 1353-2	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Study No. 0-1353	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080				13. Type of Report and Period Covered Interim: September 1993 - November 1994	
				14. Sponsoring Agency Code	
15. Supplementary Notes Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration Research Study Title: An Evaluation of High-Occupancy Vehicle Projects in Texas					
16. Abstract This report documents the verification and validation of two methods which estimate the potential mobile source emission reduction of high occupancy vehicle (HOV) facilities. A brief overview of HOV mobile source emission evaluation methodologies currently available for use, verification and validation of the San Diego Association of Governments' Transportation Control Measures Tools and the U.S. Environmental Protection Agency-sponsored Systems Applications International procedure, the recommended modifications of the SAI procedure to enhance the method's logic, and guidelines for the use of the modified SAI procedure are included in this report.					
17. Key Words High Occupancy Vehicles, Mobile Source Emissions, Air Quality Analysis, Transportation Control Measures, Systems Applications International, San Diego Association of Governments			18. Distribution Statement No Restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161		
19. Security Classif.(of this report) Unclassified		20. Security Classif.(of this page) Unclassified		21. No. of Pages 100	22. Price



**MOBILE SOURCE EMISSION IMPACTS OF
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by

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Research Report 1353-2
Research Study Number 0-1353
Research Study Title: An Evaluation of High-Occupancy
Vehicle Projects in Texas

Sponsored by
Texas Department of Transportation
In Cooperation with
U.S. Department of Transportation
Federal Highway Administration

November 1994

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135



IMPLEMENTATION STATEMENT

This research will assist metropolitan planning organizations and state departments of transportation in determining the potential mobile source emission benefits from the implementation of a HOV facility. The research includes a validation study of the San Diego Association of Governments (SANDAG) method and Systems Application International (SAI) method of determining HOV mobile source emission potentials and presents results of the validation study and recommendations. A modified version of the SAI method is recommended for use.



DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. Additionally, this report is not intended for construction, bidding, or permit purposes. Dr. Dennis L. Christiansen, P.E. (Registration Number 37961), is the Principal Investigator for the project.



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SUMMARY

The Clean Air Act Amendments (CAAA) of 1990 mandate that areas with air pollutant concentrations above national standards must follow the regulatory guidelines laid out in the Amendments to bring the area up to attainment of the standards. The CAAA were enacted to reduce the extent of mobile source emissions in urbanized areas. Transportation control measures (TCMs) are required in areas designated as severe or extreme ozone nonattainment areas. High occupancy vehicle (HOV) lanes are among the 16 control measures listed by the Environmental Protection Agency (EPA). Failure to comply with CAAA requirements can result in sanctions against the state, including the withholding of federal highway funding. Techniques used to evaluate the potential emission reduction of HOV lanes are developing rapidly. It is important for nonattainment areas to have access to methodologies which can assess the potential emission reduction from high occupancy vehicle (HOV) facilities.

The objective of this research was to verify and validate two methods which estimate the potential mobile source emission reduction of HOV facilities and select or modify one of these methods for use in Texas. Furthermore, guidelines for the methods use are provided. These methods were the San Diego Association of Governments' (SANDAG) TCM Tools and the U.S. EPA sponsored System Applications International (SAI) procedure. These methods were previously converted to spreadsheet by the Texas Transportation Institute (TTI). The methods were verified before validation was attempted. The research focused on the Houston, Texas, HOV network and adjacent mixed-use freeway lanes.

Results obtained from the SANDAG and SAI methods are not consistent with the implementation of HOV facilities. Congestion and air quality benefits gained from HOV facilities are due to a shift from single occupant vehicle (SOV) work trips to HOV work trips which reduce the total number of vehicle work trips. The mode shift was not represented by the methods. It was difficult to validate these methods based on actual emissions reductions because of the current state of technology and availability of emission data. Traffic characteristic data was used in lieu of the emission data because it was readily

available and is fairly accurate. Both models failed validation because they were not able to accurately estimate the observed changes in travel characteristics due to the implementation of HOV facilities.

Three primary recommendations were developed from the study. First, the SAI method showed the greatest potential for future use; however, it must be modified to account for HOV trips by trip purpose and include a more conservative speed change methodology. Second, traffic characteristic data are the best data source for model validation due to the current state of technology. Finally, more research is needed to determine the validity of methods which assess the potential emission reduction of HOV facilities.

The guidelines for use of the modified SAI method include details on the modifications which primarily focus on the trip change and speed change estimation logic. The guidelines consist of three general components: the required data, the travel module, and the emissions module. The guidelines are useful to state and local agencies by providing a procedure to demonstrate potential mobile source emission benefits of HOV facilities.

CHAPTER I: INTRODUCTION

BACKGROUND

The Clean Air Act Amendments (CAAA) of 1990 mandate that areas with air pollutant concentrations above national standards for any of six pollutants must follow the regulatory guidelines laid out in the Act to bring the area to attainment of the standards. Mobile sources are major producers of air pollution, generating volatile organic compounds (VOCs) and nitrogen oxides (NO_x) that contribute to the formation of ozone and also producing the majority of the carbon monoxide (CO) pollution. The transportation sector is responsible for assisting air quality agencies in estimating the current and future amount of pollution being emitted from mobile sources and in implementing control measures to reduce mobile source pollution (1).

The CAAA were enacted to reduce the extent of mobile source emissions in urbanized areas. Transportation control measures (TCMs) are required in areas designated as severe or extreme ozone nonattainment areas. The Environmental Protection Agency (EPA) lists 16 TCMs in their guidance document, but additional TCMs may also be implemented if they are shown to reduce mobile source emissions. High occupancy vehicle (HOV) lanes are among the 16 control measures listed by the EPA (2). The specific TCM that pertains to HOV lanes in the CAAA is described in Section 108(f). It states, "Restriction of certain roads or lanes to, or construction of such roads or lanes for use by, passenger buses or high occupancy vehicles."

Failure to comply with CAAA requirements can result in sanctions against the state, including the withholding of federal highway funding. However, HOV lane construction is explicitly exempt from such sanctions.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 complements the CAAA by providing flexible funding to states in order to carry out many of the transportation programs and projects required under the CAAA. The Congestion Mitigation and Air Quality Improvement (CMAQ) program was created under ISTEA to direct funds to projects and programs that will help certain nonattainment areas achieve the national air quality standards. CMAQ funds can be used for HOV construction (3).

PROBLEM STATEMENT

State and regional transportation planning agencies need to be able to evaluate the impacts of HOV lanes on mobile source emission reduction. The development of a methodology for assessing the mobile source emissions reduction potential of HOV lanes is of paramount importance considering the potential funding resources of CMAQ. If an HOV system can be demonstrated to reduce mobile source emissions, then CMAQ funding becomes available. Furthermore, in order for nonattainment areas to evaluate State Implementation Plan (SIP) strategies, the emissions impact of each considered TCM must be known.

In developing an HOV emissions reduction potential methodology several needs must be considered. The verification and validation of a methodology using real-world input data must be conducted and the accuracy of the output determined. The methodology must be evaluated using data from actual HOV field experience and tested on a network level. EPA's MOBILE5a model is the required source of emission rates; its strengths and weaknesses for use in the HOV emission reduction potential assessment methodology need to be assessed.

Finally, a methodology must be developed from the verification and validation assessment. A method will be selected and modified, if needed, for use in Texas. General guidelines for the use of the HOV emission reduction potential assessment methodology will be provided.

OBJECTIVES/SCOPE

The primary objectives were to verify and validate two separate methods which estimate the mobile source emission reduction potential of HOV facilities that rely on the EPA's MOBILE5a model for emission rates and to develop a Texas methodology from the assessment. The process of determining whether the model is performing as intended is called verification. Verification checks the translation of the model to a correctly working computer program. Validation is the process of analyzing whether or not the model replicates the real world. A component of validation is model calibration which is the assessment by which certain model variables are varied to increase the model's capability

to mimic real world situations (4). Furthermore, the strengths and weaknesses of the MOBILE5a model will be identified for the application.

The scope of this report is limited to Houston, Texas's HOV network, and corresponding single occupancy vehicles (SOV) lane corridors. The validation of the methods will be accomplished using the Houston HOV system, Automatic Vehicle Identification System (AVI) data, and extensive Houston HOV experience data collected by the Texas Transportation Institute (TTI). AVI data will be obtained for HOV and non-HOV corridor lanes in the Houston highway network. Because Houston is categorized as a severe ozone nonattainment area, the accuracy of potential mobile emission reductions from HOV that will aid in conformity to air quality guidelines must be assessed. The validation study will use data corresponding to the summer ozone season in Houston.

The validation and verification study will be conducted using the San Diego Association of Governments (SANDAG) method and the Systems Application International (SAI) method for estimating HOV mobile source emission reduction potential. These methodologies were previously converted to spreadsheet format by TTI and integrated with MOBILE5a. One of these methods or a modification of one of these methods will be chosen for use in Texas.

ANTICIPATED BENEFITS

Better methods of estimating emission benefits from the implementation of a single or systemwide HOV projects are needed to assist Metropolitan Planning Organizations (MPO) in creating Transportation Improvement Programs (TIP) and the state of Texas in creating the State Implementation Plan (SIP). Furthermore, the mobile source reduction emission potential of HOV facilities must be well documented in order to meet Federal Highway Administration/EPA criteria for obligation of CMAQ Program projects. Texas is appropriated approximately \$90 million of CMAQ funding per year. As of the end of fiscal year 1993 the Texas obligation of CMAQ funds is 18 percent, well below the national average of 50 percent (5). If the emission reduction potential of an HOV facility can be demonstrated by the verification and validation of either of the two models, it may provide a possible enhancement to the CMAQ obligation rate of the state of Texas because HOV

facilities will become more attractive to CMAQ funding. Methodologies for estimating the mobile source emission reduction potential of HOV lanes are still in their infancy, and a critical analysis of current methods may assist in the development of improved methodologies.

ORGANIZATION OF THE REPORT

This report is organized into five chapters. The first chapter provides a general overview of the problem and the events that have brought about this study. Chapter II discusses methodologies to evaluate the mobile source emission reduction potential of HOV facilities. The Chapter III describes the study design. Chapter IV presents the results of the analysis. Finally, Chapter V offers conclusions and recommendations, and also contains the proposed HOV mobile source emission assessment methodology and guidelines for its use.

CHAPTER II: LITERATURE REVIEW

TRANSPORTATION CONTROL MEASURES

TCMs are one of the tools available to reduce mobile source emissions. Required in severe and extreme nonattainment areas, TCMs may be implemented in any nonattainment area or even in attainment areas. TCMs must be submitted to the EPA in the SIP for attaining air quality standards. In order to receive federal highway funding, TCMs must also be included in the area's TIP and metropolitan transportation plan.

HOV lanes are among the 16 TCMs suggested by the CAAA. HOV lanes are thought to reduce trips and vehicle miles traveled (VMT) by providing incentives (travel time savings and trip time reliability) for travelers to use buses, carpools, and vanpools. Reducing VMT is generally considered the most effective mobile source control, because improvements in vehicle emission control technology, congestion mitigation, and other emission reduction strategies historically have been offset by VMT growth.

The EPA guidance document, *Transportation Control Measure Information Documents*, cites studies conducted in three urban areas with HOV systems: the San Francisco Bay area, Houston, and New York City. In all three cities the mobile source emission impacts of HOV systems/lanes were found to be beneficial (2). The three case city experiences are described below.

San Francisco's Metropolitan Transportation Commission adopted a "2005 HOV Lane Master Plan" in May 1990. The Master Plan is the first step in a comprehensive plan to promote HOV lanes in the Bay area, thereby reducing SOV travel and reducing mobile source emissions. The plan calls for adding to the existing 77 miles of HOV lanes in two phases, creating more than 300 miles of new HOV lanes by 2005. Researchers found travel time savings to be an important determinant of HOV usage. They discovered that HOV usage increases significantly when trip time was reduced by 15 minutes or more. Transportation researchers found other incentives to use HOV lanes were support facilities including park-and-ride lots, employer-based trip reduction programs, and reduced commuter parking subsidies. An analysis was performed for the 2005 plan in which HOV lanes were assessed as a regional system of facilities that would be an integral part of the region's primary roadway network. The analysis results indicate that

regional peak-period VMT in the year 2005 would be reduced by less than 1 percent compared to the do-nothing alternative; however, VMT during the morning peak hour would be decreased by 5 percent. Carbon monoxide emissions as a result of work trips would be reduced by 3 percent, and hydrocarbon emissions would decrease by 2.3 percent on a regional basis (2).

Houston has the most extensive network of barrier-separated HOV lanes in the country. Although air quality was a secondary consideration when building the system, the passage of the CAAA and Houston's designation as a severe ozone nonattainment area have brought new interest to the mobile source emission reduction benefits of Houston's HOV lanes. In 1990, all HOV lanes required a minimum of two passengers per vehicle, except the Katy Freeway which required three or more passengers. The Katy Freeway requirement was instituted as a result of morning peak congestion on the system; after raising the number of required passengers from two to three per vehicle, high speeds and reliable trip times were restored. In addition to reliable trip times, another important incentive in the Houston system is the availability of park-and-ride lots along the major corridors, some of which are located at access points to the HOV lanes, as are some transit centers. The majority of people (60 percent) using HOV lanes travel by carpool or vanpool, while 40 percent are bus transit riders. Researchers found bus ridership increased by 345 percent on the Katy Freeway and by 135 percent on the Northwest Freeway after completion of the HOV lanes. TTI researchers predict that HOV VMT may actually increase in the future due to new carpools and buses; however, HOV lanes will produce fewer emissions in the corridor and serve more growth in person movement than would conventional capacity additions (2).

New York City has a bus lane program that was implemented in response to the CAAA. The bus lane program was designed to address carbon monoxide "hot spots" in the city. The bus lanes include restricted right lanes where only buses and right-turning vehicles are allowed in the right-hand lane, exclusive lanes, where one or two lanes are physically separated from other traffic by cones, heavy markings, or other means, are devoted exclusively to buses. Other parts of the program provide for transit streets which are entirely devoted to transit operations (with some access for goods movement and garage entries), and queue bypass traffic signals which allow buses to bypass waiting traffic at certain high-use intersections.

New York's HOV system increases transit use while increasing the people-moving capacity of the city street system. Separating buses from the general traffic flow also decreases

congestion in the general use lanes. New York has 30 miles of streets with bus lanes carrying 415,000 passenger trips on a daily basis. Researchers performed a CO air quality analysis on 2nd Avenue and found that CO emissions dropped by 90 percent after implementation of a bus lane. Overall, researchers found that trip times decreased, speeds increased, and transit ridership increased (2).

In their TCM information document, EPA states that "Travel demand assessments of how well HOV lane facilities reduce system-wide emissions have indicated that reductions would amount to less than [1 percent]. . . . Corridor emission reductions of a single HOV lane, however, may be much greater, and more recent research has shown that larger systems of HOV facilities may have correspondingly more significant impacts on regional emissions"(2).

Criticism of the Purported Emission Reduction Benefits of HOV Lanes

Some critics of HOV lanes propose that HOVs may actually *increase* mobile source emissions in the long run due to several reasons. Criticisms include the following (1):

- Allowing vehicles with only 2+ occupant levels does not offset the numbers of new solo drivers that take up the lane space vacated by HOV users.
- HOV lanes attract riders away from transit.
- VMT may increase over growth predictions due to latent travel demand and the maxim "if you build it, they will come." A "take-a-lane" approach provides more incentive to use HOV lanes and discourage SOV use than an "add-a-lane" approach. "Take-a-lane" causes more congestion initially, whereas "add-a-lane" encourages both HOV users and new SOV users to drive on the less-congested roads.
- California Air Resources Board (CARB) predicts that if they can increase their average vehicle occupancy to 1.5 by the year 2000 through use of HOVs, they will decrease their mobile source emissions by 5 to 10 percent (6). However, a study performed one month later for the SANDAG found building HOVs to be the least cost-effective control measure of all of the TCMs (7).

- The high speeds of HOVs are thought to decrease emissions, but recent CARB findings show that emissions of NOx are actually higher when speeds are above the range of 30 to 40 miles per hour.
- HOVs encourage carpooling more than they encourage transit.
- Park-and-ride lots cause more cold start emissions because people are making short trips to the lots. While it is better to pick up people at or close to their homes when carpooling, VMT may increase by forcing the driver of the carpool vehicle to drive extra miles to pick everyone up, thereby offsetting the gains made.

METHODOLOGIES

The EPA has not issued any methodologies for estimating TCM benefits. Since there are no federal guidelines, some nonattainment areas have contracted with consultants or researchers to develop appropriate methodologies for evaluation of TCM benefits. This section discusses some of the methods in use or being developed.

SANDAG Methodology

Sierra Research, Inc., together with JHK & Associates, have developed a TCM package for use in California. The methodology is documented in "User Manuals for Software Developed to Quantify the Emissions Reductions of Transportation Control Measures" (7). This method, which was prepared for and known as SANDAG, is made up of the following modules:

- A travel module which computes the impacts of individual TCMs on travel parameters (trips, VMT, and speed),
- An emissions module which combines estimates of the TCM-specific travel impacts with emission factor data contained in EMFAC7E and BURDEN7c to develop an estimate of baseline emissions and pollutant reductions for each TCM, and
- A cost-effectiveness module which combines estimates of travel impacts and emissions reductions with information on TCM-specific implementation costs to estimate cost effectiveness of individual TCMs.

The SANDAG method is designed to predict the effect of single TCMs and was developed using LOTUS 1-2-3 and FORTRAN. The method was devised for several air basins and counties in California to encourage greater use of the method in the state (8). The travel module estimates the changes in number of trips, in VMT, and in speeds from TCM implementation. Inputs for this method include baseline travel characteristics, TCM-specific parameters, and underlying assumptions. The SANDAG method uses several elasticities which are based on empirical data from the western U.S. The changes in travel impacts are differentiated by travel period: peak or off-peak. In addition, the method determines the effects on work and non-work trips; however, trip type and time period are not correlated (e.g., peak work trip, off-peak work trip, peak non-work trip, and off-peak non-work trip). The method does not estimate the effects of latent demand and indirect trips. Indirect trip effects are those caused by a commuter leaving the vehicle at home and another family member using the vehicle for other purposes. Latent travel demand is the demand attracted to a roadway because of improved conditions (less congestion). The indirect trip effect is an important consideration for modeling the real world, because not all vehicles will be left at home when a commuter changes modes of transportation. The effect of latent travel demand is a required user input and difficult to estimate.

Analysis of the impacts of HOV lanes is based on the following procedures. The analyst gathers baseline travel characteristics which include: total peak VMT, total commute vehicle trips, percentage of peak trips that are commute trips, average commute trip length, percentage of all trips in peak period, and percentage of VMT on freeways. TCM-specific parameters, also supplied by the user, include miles of freeway affected, number of hours in peak periods, number of existing lanes on freeway, induced number of vehicle trips on mixed-flow lanes due to additional capacity, and percentage of freeways affected. Assumptions in the methodology include peak-period elasticity of speed with respect to volume and average mode shift from drive alone per mile of HOV lane per hour. Furthermore, it is assumed that only peak-period travel is affected. The SANDAG method calculates the following measures:

1. Reduction in peak trips
2. Reduction in off-peak trips
3. Reduction in total trips
4. Reduction in peak VMT

5. Reduction in off-peak VMT
6. Reduction in total VMT
7. Existing VMT on affected freeways
8. Revised VMT on affected freeways
9. Percentage change in peak speeds
10. Percentage change in off-peak speeds

The program output consists of speed change, number of trips affected, and VMT reduction; the estimated emission benefit reduction potential is calculated for VOC and NO_x in tons/day and percent reduction. For HOV, measures 2, 5, and 10 are assumed to be zero, because HOV lanes typically operate and only affect peak-period traffic.

SAI Methodology

SAI has also developed a methodology which is documented in "Methodologies for Estimating Emission and Travel Activity Effects of TCMs (9)." The SAI methodology is the most recent attempt by the EPA to estimate the potential emission benefits from the implementation of TCMs. Its basic structure consists of two modules: travel effects and emission effects. The SAI methodology estimates trip, VMT, and speed changes from selected TCMs. These variables represent critical data required to evaluate the effectiveness of TCM implementation. Direct trip reductions and indirect trip increases, as well as trip shifts into and out of the peak period, are calculated (8). VMT changes are calculated based on trip changes and changes in trip length. Speed changes are determined from VMT changes.

Trip types (work and non-work) are associated with their time of occurrence (peak and off-peak). This organization of trips provides an accounting system which includes all trips that occur in a region. Through this accounting process, an enhanced estimation of TCM effects can be made since TCMs can be applied in the peak period, off-peak period, or both.

The methodology provides guidance on estimating indirect trip effects and latent travel demand. Unlike the SANDAG method, the SAI method attempts to quantify latent travel demand; however, SAI does not add the latent travel demand effects into the overall travel effects estimates. Calculations in the SAI method:

1. Identify the potential direct trip effect and the trip type affected

2. Calculate the direct trip reductions
3. Calculate the indirect trip increases
4. Determine direct peak/off-peak period trip shifts
5. Calculate the total trip changes
6. Calculate the VMT changes due to trip changes
7. Calculate the VMT changes due to trip length changes
8. Determine the total VMT changes
9. Calculate speed changes

The output of the SAI methodology is in the same format as the SANDAG methodology which includes speed change, number of trips affected, and VMT reduction; furthermore, the estimated emission benefit reduction potential is calculated for VOC and NO_x in tons/day and percent reduction.

CARB Methodology

CARB recommends that "all urban nonattainment areas include an HOV system plan as part of their air quality management plan." Their methodology for estimating the mobile source emission reduction potential of HOV facilities covers the following (6):

1. Primary emission benefits (fewer cold starts, hot soaks, hot starts, and diurnal emissions)
2. Congestion-reduced emission benefits (less congestion due to HOV use)
3. VMT-reduced emissions benefits (fewer vehicles on the roadway)
4. Total primary emissions benefits (congestion-reduced emission plus VMT-reduced emission benefits divided by total emissions times 100 equals percentage reduction in total emissions)
5. Secondary emission impacts (as trips and congestion are reduced on freeways, emissions from arterial travel will be reduced where home pickup carpools are formed or alternative modes of travel are used).

Sierra Methodology

Sierra Research, Inc., under subcontract to SR Consultants, has developed a TCM software package for use by the Houston-Galveston Area Council (HGAC) (10). This package is based on the SANDAG method and consists of the same three modules. The analysis procedures are similar, except for the following differences: the average non-commute trip length is factored into the methodology, and only one HOV lane is assumed affected. The Sierra and SANDAG methods are also similar with respect to calculations and outputs.

Latent Travel Demand Methodology

A recent study developed and applied a simulation methodology for estimating vehicle emission impacts of modal shifts from private vehicles in the freeway main lanes to buses in an HOV lane when latent travel demand is considered (11). The results indicated that reductions in VMT do not necessarily result in reductions of vehicle emissions for all three pollutants even when latent travel demand is not considered. This is because NO_x emissions increase as speed increases. *FREQ10PL*, a macroscopic simulation model, was used to simulate freeway traffic; and EPA's *MOBILE* model was used to estimate emissions. The simulation provided estimates of VMT on the freeway, the average speed for each freeway subsection, and the ramp delay. The simulation involved varying the mode shift from the main lanes to the HOV lanes and varying the amount of reduction in travel on the main lanes that was filled by latent travel demand. The study illustrates some of the difficulties that arise in evaluating the potential emission reduction benefits of HOV lanes.

MOBILE5a HIGHWAY VEHICLE EMISSION REDUCTION FACTOR MODEL

The *MOBILE5a* emission factors are used by some models to estimate the mobile source emission reduction potential of HOV lanes. *MOBILE5a* is a highway vehicle emission factor model that calculates HC, CO, and NO_x emission factors in grams per mile for eight vehicle types for 1960 to 2020 calendar years for a range of user-specified conditions. It is the latest version of the *MOBILE* model released by the EPA and is required by the EPA unless a waiver is granted to use another model. Texas nonattainment areas use *MOBILE5a*. *MOBILE5a* is

coded in FORTRAN and is flexible in many of its inputs. All default values are national averages. An overview of the MOBILE5a model follows (12).

Basic model assumptions include emissions calculated individually for each model year, all emissions expressed as averages, vehicle age measured by mileage, and all defaults as national averages.

Vehicle emission sources are exhaust (tailpipe), non-exhaust (fuel evaporation), and refueling. Basic emission rates depend upon vehicle type, emission standards, vehicle technology, and vehicle age in miles. Adjustments to the basic emission rates include average vehicle speed, regional ambient temperature, fuel type, vehicle operating mode (e.g., cold or hot), and in-use control programs (inspection and maintenance).

Factors that MOBILE5a considers in calculating vehicle emission deterioration are normal deterioration (wear and tear), maintenance (neglect), and emission control damage or removal (tampering). In-use control programs can be used to identify high-emitting vehicles in order to repair those same vehicles to meet emission standards. In-use control programs are the best method of maintaining vehicle fleet emission standards.

MOBILE5a has several operator-/user-specified fleet parameters to enhance model performance. The user specified fleet parameters are VMT distribution among vehicle types, representative vehicle distribution by age, average mileage accumulation by age, diesel sales by model year, and vehicle operating mode by VMT.

SUMMARY

Methodologies for assessing the mobile source emission reduction potential of HOV lanes have been used only since late 1991. Models currently available for use were developed for California nonattainment areas. For Texas nonattainment areas to meet SIP requirements, there is an urgent need for a methodology utilizing MOBILE5a.

Much remains to be discovered about the relationship between HOV facilities and their impact on mobile source emission reductions. Researchers have only recently begun studying this issue. Methodologies are still being developed and tested. Most of the early work was done using California's EMFAC emission factor model. Results of programs designed to use EPA's

MOBILE5a emission factor model have yet to be analyzed. California methods, SAI and SANDAG, use the EMFAC7E emission rate models; whereas Texas uses MOBILE5a.

A validation and verification analysis of the California methods converted for use with MOBILE5a will be performed to determine the feasibility of the application of these models to assess HOV mobile source reduction potential for Texas. Data from Houston will be used to test the validity of the models.

The SAI and SANDAG methodologies are at the forefront of sketch-planning methods to evaluate emission reduction potential of HOV lanes. The validation and verification analysis of these methodologies will determine if one, both, or neither method is suitable for use in Texas for assessing HOV mobile source emission reduction potential associated with individual HOV projects and HOV systems.

CHAPTER III: STUDY DESIGN

INTRODUCTION

The focus of this study is verification and validation of the SANDAG and SAI methods for assessing the mobile source emission reduction potential of HOV facilities and the selection of a Texas methodology from the results of the analysis. The SANDAG and SAI methods have been selected for verification and validation purposes because they were evaluated as the best methods currently available. This chapter is organized into four major sections. The first section describes the study area and the HOV facilities in the study area. The second section describes the SANDAG and SAI methods' requirements to run the computer models; it primarily focuses on the data requirements. The third section details the validation data requirements and their sources. The fourth section describes the analysis procedure and explains how the data gathered in sections two and three are used for the validation of the methods. A Texas HOV mobile source emission assessment methodology will be selected based on the results of the verification and validation study.

DESCRIPTION OF THE STUDY AREA

The data used was for the Houston HOV system. Houston was selected as the study site based on three criteria: it is a nonattainment area; it is a large, urbanized area with a developing, extensive HOV system; and TTI has done extensive data collection in the greater Houston area.

Houston is located in southeast Texas on the Gulf of Mexico. The city's population is 1,888,337 making it the largest city in Texas and the fourth largest in the U.S. (13). Houston has the largest concentration of petrochemical plants in the nation. The port of Houston is the largest wheat exporting port and ranks in the top ten ports of the U.S. The city sits at an altitude of 6 feet above sea level. The extensive urban sprawl, high traffic volumes, and intensity of industry cause Houston to have the second worst air quality in the nation.

HOV experiences on the Shirley Highway in Virginia and the San Bernadino Freeway in Los Angeles were highly successful and led Houston METRO to a commitment to develop an HOV system. Houston has committed to develop approximately 96 miles of HOV lanes. As of December 1990, four separate HOV facilities were in operation in the Houston area. Table 1

summarizes the HOV facilities and their scale and operation. Figure 1 shows the layout of the Houston HOV system and the 1990 development stage. In 1990, a total of 46.5 miles of barrier-separated, HOV lanes were operating (14).

Table 1
Houston HOV System Status, 1990

HOV Facility	Date First Phase Opened	Miles in Operation	Ultimate System Miles	Required Vehicle Occupancy	Weekday Hours of Operation
Katy (I-10)	Oct 1984	13.0	13.0	3+ vehicles from 6:45 to 8:00 a.m. 2+ during other operating hours	4 a.m. to 1 p.m. inbound 2 p.m. to 10 p.m. outbound
North (I-45)	Nov 1984	13.5	19.7	2+ vehicles	same as Katy
Gulf (I-45)	May 1988	6.5	15.5	2+ vehicles	same as Katy
Northwest (US 290)	Aug 1988	13.5	13.5	2+ vehicles	same as Katy
Southwest (US 59)	Not Opened in 1990	0.0	13.8	N/A	N/A
Eastex (US 59)	Not Opened in 1990	0.0	20.0	N/A	N/A
Total		46.5	95.5		

Source: TTI Research Report 1146-4 (14)

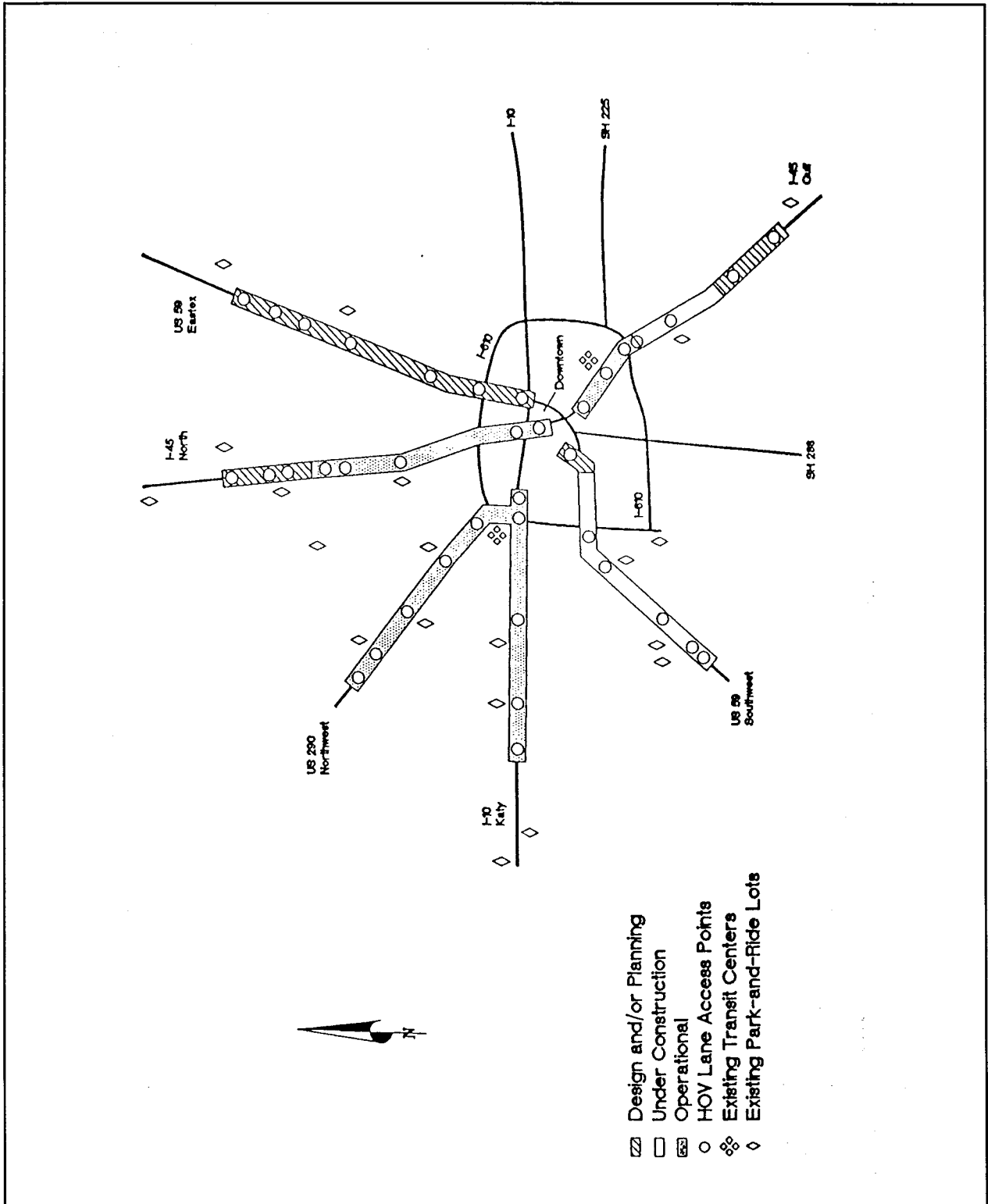


Figure 1. Planned Houston HOV System (adapted from [14])

METHODOLOGY REQUIREMENTS

Hardware and Software Requirements

The SAI and SANDAG methodologies require a 386K microprocessor with 4 megabytes (MB) of memory and 2.5 MB of hard-disk space. The methodologies were converted to spreadsheet use by TTI. The spreadsheets require operation with Microsoft Excel version 5.0 and Microsoft Windows operating environment version 3.0 or greater.

Data Collection Requirements

Numerous inputs are required in order to use the SAI and SANDAG models. The HOV TCM evaluation inputs include travel characteristics, travel behavior, demographics, and emission factor data. More than 75 variables were identified for evaluating the HOV TCM with the SANDAG and SAI models. The data collection sources are also widely varied. The primary potential generic sources of data collection are The City and County Data Book (15), federal census data, local and state transportation departments, local transit agencies, local metropolitan planning agencies, local and state ridesharing agencies, and the Texas Almanac (13). If data were unavailable or untrustworthy, the model default values were used. Default values are used only as a last resort, because they were developed in varying geographical areas and urban transportation infrastructures.

The calendar year of 1990 was chosen for the analysis because of the strength of the available data. Calendar year 1990 was a census year which improved the accuracy of the demographic data required of the model. Furthermore, 1990 is the base year accepted for the EPA for emissions inventory. All air quality standard projections are based on this year. If future comparisons of the HOV mobile source emission potentials were to be evaluated, then an accepted base year emission inventory is necessary. Another strength of 1990 data is that TTI has gathered extensive data on Houston HOV experience. The 1990 TTI Research Report 1146-4 (14), contains well-documented data vital to the analysis of the Houston HOV system using the SANDAG and SAI methodologies. The required data and data source for the SANDAG model are contained in Tables 2, 3, and 4. The required data and data source for the SAI model are recorded in Tables 5 and 6.

Table 2
SANDAG Model Baseline Data Requirements

Baseline Travel Characteristic	Value (Source)
Total peak VMT	40,314,462 Houston Galveston Area Council (HGAC)
Total commute vehicle trips	1,906,668 (HGAC)
Percentage of peak trips that are commute trips	29.74 (HGAC)
Percentage of commute trips in peak period	64.28 (HGAC)
Percentage of non-commute trips in the peak period	35.19 (HGAC)
Average commute trip length	13.9 miles or 21.8 minutes (HGAC)
Average non-commute trip length	7.5 miles or 12.3 minutes (HGAC)
Percentage of all trips in peak period	40.66 (HGAC)
Percentage of VMT on freeways	48.79 (HGAC)

Table 3
SANDAG Model TCM-Specific Requirements

TCM-Specific Parameter	Value (Source)
Miles of freeway affected	47.5 miles (HGAC)
Number of hours in peak periods	5.0 hours (HGAC)
Number of existing lanes on freeway (all)	5.0 lanes (HGAC)
Induced number of vehicle trips on mixed-flow lanes due to additional capacity	0 (for model validation)
Percentage of freeways affected	8.4 (HGAC)
Number of park-and-ride lot spaces provided	9,000 spaces (HGAC)
Average utilization rate of park-and-ride lot spaces	47 (HGAC)
Percentage of park-and-ride lot use that is commute trips	99.6 (HGAC)
Average length of trip to park-and-ride lot	5.3 miles (HGAC)

Table 4
SANDAG Model Assumptions

SANDAG Assumptions	Value (Source)
Peak elasticity of speed with respect to volume	-1.295 (HGAC)
Average mode shift from drive alone per mile of HOV lane per hour	98 (HGAC)
Only peak-period travel is affected	Model Assumption

Table 5
SAI Model Baseline Data Requirements

Baseline Travel Characteristic	Value (Source)
Total number of trips/day	12,501,209 (HGAC)
Percentage of work trips to total trips/day	18.81% (HGAC)
Fraction of population that does not own a vehicle	.289 (1990 Census)
Fraction of trips made via shared mode	.286 (SAI Default)
Average household size	2.75 (1990 Census)
Fraction of population that is employed (16 years+)	.67 (1990 Census and Texas Almanac)
Work trip generation rate for SOV users (trips per day)	2.0 (previous study assumption)
Non-work trip generation rate for SOV users (trips per day)	3.25 (previous study assumption)
Fraction of population that is unemployed (16 years+)	.069 (Texas Almanac unemployment rate)
Elasticity of mode choice with respect to cost	-.40 (SAI Default)
Average work trip length (min)	21.8 minutes (HGAC)
Regional hourly wage	\$11.74 (1990 Texas Almanac)
Daily out-of-pocket commute cost (does not include Operation and Maintenance of vehicle)	\$.03 (previous study assumption)
Total trips per day affected by the speed increase	567,043 (HGAC- commute trips in peak period)
Fraction of non-work trips of the total TCM-related non-work trips during the peak period	1.00 (Model requirement)

Table 5 Continued

Baseline Travel Characteristic	Value (Source)
Fraction of work trips of the total TCM-related work trips during the peak period	1.00 (model requirement)
Fraction of work VMT that occurs in the peak period	.2974 (HGAC)
Average work trip length (miles)	13.9 miles (HGAC)
New work trip length (miles)	5.3 miles (HGAC- distance to Park and Ride lot)
Average non-work trip length (miles)	7.5 miles (HGAC)
Total regional population	2,782,414 (1990 Texas Almanac)
Elasticity of peak speed with respect to volume	-1.295 (HGAC)
Elasticity of off-peak speed with respect to volume	-0.017 (HGAC)
Total VMT in peak period	40,314,462 (HGAC)
Total VMT in off-peak period	55,946,859 (HGAC)
Length of AM peak period in hours (2,2.5,3,3.5,4)	2 hours (HGAC: 6:30 - 8:30 a.m.)
Length of PM peak period in hours (2,2.5,3,3.5,4)	3 hours (HGAC: 3:30 - 6:30 p.m.)
Number of work trips per vehicle commute day	2 (previous study assumption)
Number of non-work trips per day per vehicle	5 (previous study assumption)
Peak-period speed prior to TCM implementation (mph)	30 mph (previous study assumption)
Off-peak-period speed prior to TCM implementation (mph)	40 mph (previous study assumption)

Table 6
SAI Model TCM-Specific Parameters

TCM-Specific Parameter	Value (Source)
Average speed on mixed-use freeway lanes	40.5 mph (TTI Report 1146-4)
Average speed on HOV lane(s)	57.2 mph (TTI Report 1146-4)
Number of people trips on the affected freeway(s)	319,219 (HGAC)
Average vehicle occupancy (AVO)	1.09 (1990 Census and Texas Average Occupancy Model)
HOV elasticity of peak speed with respect to volume	-1.5 (TTI)
Peak-period commute vehicle trips	1,235,974 (HGAC)
Total peak-period vehicle trips	4,039,224 (HGAC)
Fraction of potential trips that will use transit	.374 (SAI default)
Fraction of potential trips that will use rideshare	.626 (SAI default)
Fraction of potential trips who will use fringe parking	0.0 (SAI default)
Average number of people per carpool	2.2 (TTI Report 1146-4)
Fraction of new carpoolers who join existing carpools and don't meet at park-and-ride	.33 (SAI default)
Fraction of new carpoolers who join new carpools and don't meet at park-and-ride	.62 (SAI default)
Fraction of people who drive to the public transit station	.005 (SAI default)

MOBILE5a Emission Factor Requirements

MOBILE5a was the emission factor model used in the analysis to calculate mobile source emission factors for the Houston region. The MOBILE5a 1990 template was obtained from HGAC. Some modifications to the template were made to accommodate analysis with SANDAG and SAI models. MOBILE5a was run for speeds 10 mph to 50 mph at 0.1 mph increments. MOBILE5a was run another four times to gain idling, cold start, hot start, and hot stabilized emission factors. Thus, the model was run a total of 404 times; and the emissions factors by vehicle type were entered into the SANDAG and SAI models.

VALIDATION REQUIREMENTS

The SANDAG and SAI methods have similar outputs which require validation. The outputs are speed increase, trip reductions, VMT reductions, and emissions. Both methods base emission estimates on the changes in traffic characteristics which are the speed, trip, and VMT changes. Thus, the validation will focus on the validity of the traffic characteristic output in order to determine if the emission output of the models are reasonable. The data for speed and VMT were obtained from AVI and the Highway Performance Monitoring System (HPMS), respectively. The trip reductions output was analyzed using current HOV experience data from TTI.

Speed

Both methods estimate a regional speed reduction due to the implementation of an HOV facility. Regional speed is defined as the average speed on all the roads in the study area including freeways, arterials, collectors, and local roads. The methods assume that HOV lanes reduce congestion, thus creating a regional speed increase due to improved traffic flow conditions. The change in regional speed is determined by a relationship involving the modeled VMT changes and input elasticities. The SANDAG and SAI methods calculate the change in regional speed using the following relationships: Percentage change in peak speeds = $-(\text{reduction in peak VMT})/(\text{total peak VMT}) * (\text{peak elasticity of speed with respect to volume})$. A negative sign is included in the formula because the peak elasticity of speed with respect to volume is a negative value and, thus, is

necessary to yield the correct sign. The peak elasticity of speed with respect to volume is assumed to estimate the entire region's elasticity.

The author assumed the primary speed beneficiary from HOV facility implementation is the corresponding mixed-use freeway lanes. The models predict regional speed changes but it is hypothesized that the greatest speed changes, occur on the mixed-use freeway lanes that are adjacent to the HOV facility. The HOV lane speeds and the corresponding mixed-use freeway lane speeds were used for validation because they represent the most extreme speed change scenario. Thus, the 1994 HOV and mixed-use lane speed data were compared to 1990 HOV and mixed-use speed data for validation purposes. The 1990 HOV lane speeds and the corresponding mixed-use freeway lanes comprise the base data values used for comparison purposes. The speed data used for the validation comparison consists of 1990 and 1994 mixed-use freeway lanes adjacent to the same HOV facilities, not regional speeds. The 1990 base data values, obtained from TTI, were collected by travel time runs on the mixed-use freeway lanes (14). The 1994 data were obtained from AVI. The 1990 data were collected on the same facilities as the 1994 data. The 1990 base values were used as inputs into the the SAI model (Table 6) and used for the validation analysis for both models.

Ideally, validation of speed is conducted with before-and-after speed data. The before data consists of pre-HOV speeds on a facility where HOV construction is planned. The after data consists of speed data collected after implementation of the HOV facility. The research revealed that the before data are greater than ten years old, and Houston is arguably a different city than it was ten years ago. Because the methods do not consider population or growth factors, more current data were needed to reduce the impact of the methods not accounting for population or growth factors. Calendar year 1990 data were accepted as recent data for validation purposes; furthermore, 1990 data corresponded to the abundance of census data available. Unfortunately, a validation situation which involved 1990 after data compared to 1994 after data was instituted. The 1990 speed data are that of an HOV system which ranges in age from two to six years old compared to the 1994 data associated with a six- to ten-year old HOV facility. The lack of better data mitigated the value of the speed validation.

The AVI system in Houston is used to monitor speeds and travel time. Various technologies available implement AVI. However, there are several basic elements to each system: a vehicle mounted transponder (toll tag), a roadside reader and antenna array (i.e., roadside communication unit (RCU)), a central computer system for processing and storing account data, and an enforcement and detection system (16).

Data from the AVI system were obtained for model validation. The Houston AVI system is currently in a testing stage to determine public support and achieve system confirmation. The AVI system was used to determine main lane and HOV lane speeds. The AVI system RCU records user identification codes and time of passage. The central computer system translates the code to a license plate number. Because the distances between the RCU stations are known, the speed for each vehicle is determined using a relationship involving the vehicle time of passage and distance between RCU stations (checkpoints). Figure 2 shows the Phase 1 AVI inbound checkpoints, and Figure 3 shows the Phase 1 outbound checkpoints. The average speeds of the main lanes and HOV lanes were calculated manually from the printed central computer system output. The information obtained from the printouts included four days of averaged speeds in 15-minute periods, the number of vehicles per 15-minute period, the maximum recorded speed, and the minimum recorded speed. The average speeds of each facility were determined first and then averaged together using lane mileage as the weighing factor to determine the regional average speeds for freeway main lane and HOV lanes within the AVI system. The SANDAG and SAI modeled output speeds were compared to the actual Houston HOV network speeds taken from the AVI system to determine the models' accuracy. Table 7 shows the freeway main lane and HOV lane weighted peak-period speeds by facility and reveals the overall average (regional) speed for freeway main lanes and HOV lanes. AVI data for the Gulf Freeway HOV facility was unavailable and, thus, not used for speed validation purposes. Table 7 is a summary of AVI data collected during the peak periods of 6:30-8:30 a.m. and 3:30-6:30 p.m. for 24-27 May 1994 on the Houston AVI system. The data were the latest available during the time of the study. Houston summer traffic data were desired to conform to the summer ozone season.

Table 7
Average Weighted Peak-Period Speeds by Facility, May 1994

Facility Name	Freeway Main Lanes Average Speed	HOV Lane Average Speed
I-10 Katy	43.4 mph	59.5 mph
I-45 North	49.7 mph	55.6 mph
US-290 Northwest	51.5 mph	55.9 mph
Weighted Average	48.8 mph	56.5 mph

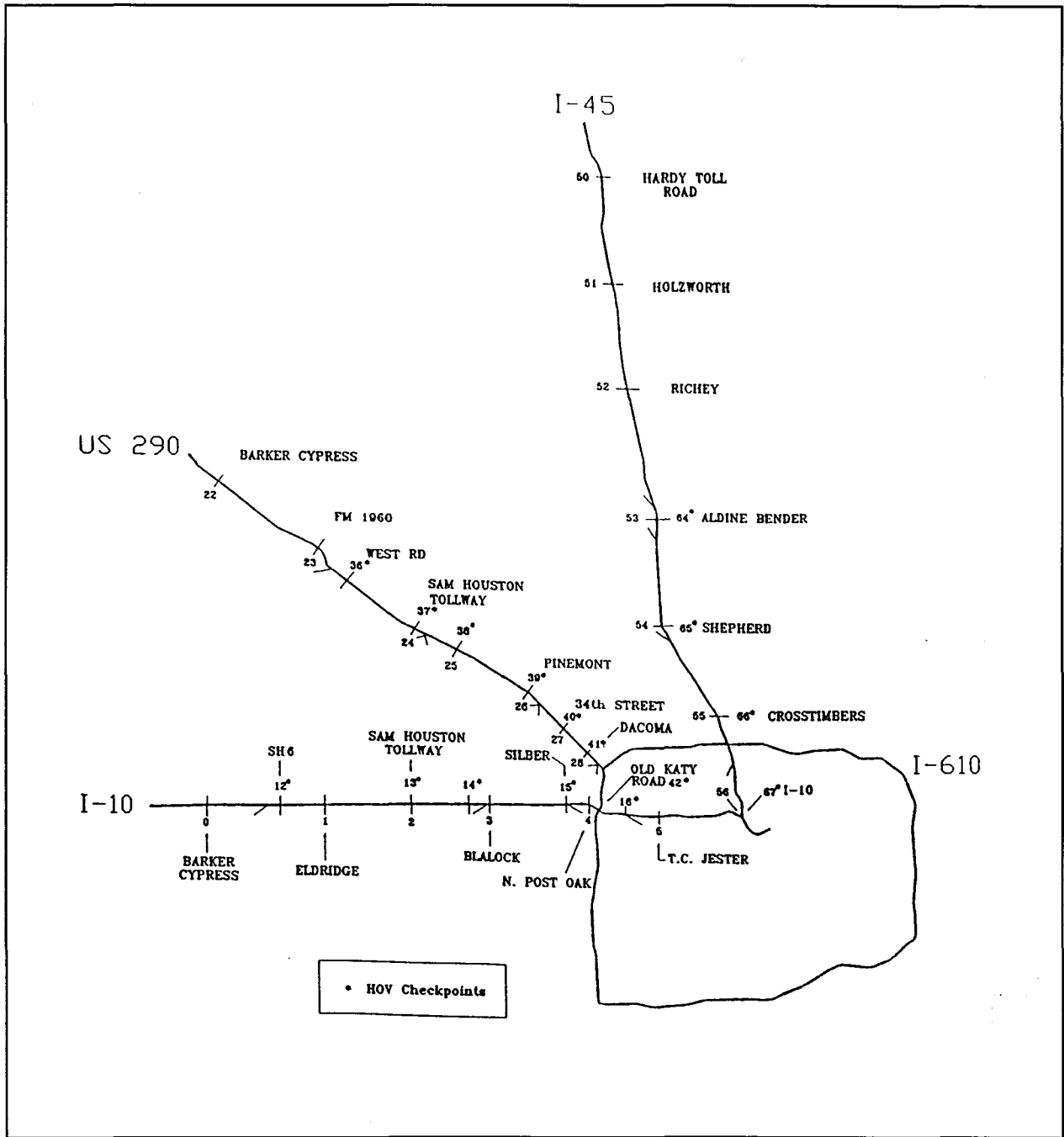


Figure 2. AVI Inbound Checkpoints

Trip Changes

Both methods estimate peak-period work and non-work trip reductions due to the implementation of an HOV facility. The methods assume that HOV lanes induce a shift from SOV to HOV, thus reducing the overall number of trips. The trip reductions are determined by

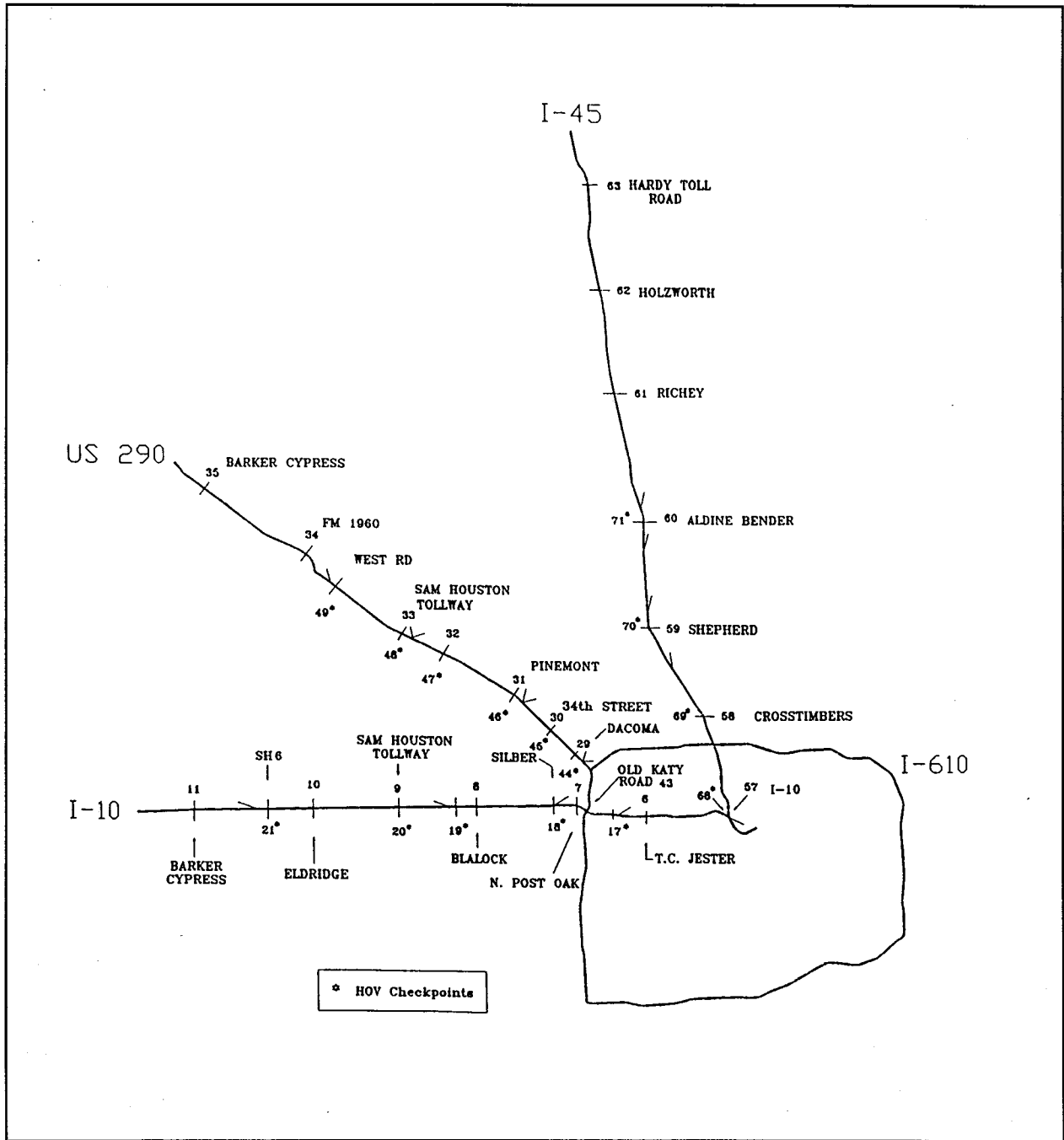


Figure 3. AVI Outbound Checkpoints

a formula based primarily on the magnitude of the SOV to HOV shift rate multiplied by the number of people trips on the affected freeways. In general, the computation consists of a participation rate multiplied by the potential number of participants. Current HOV trip experience

was used to conduct model validation. Current HOV trip experience comprises the percentage of peak-period work and non-work trips on the HOV facility during the peak period.

The predicted trip changes of the SANDAG and SAI methods were validated against current Houston HOV trip experience. The predicted trip changes are categorized as work and non-work. The modeled trip change effects were compared to the current HOV trip experience by trip purpose for similarity. If modeled trip changes are similar to the local observations, then the trip change effects of the models can be verified.

VMT

The SANDAG and SAI methods estimate the change in VMT due to the implementation of an HOV facility. The methods assume that HOV lanes induce a shift from SOV to HOV, thereby reducing the overall number of trips; furthermore, the trip length is assumed to be shortened in some cases because the commuter drives a shorter distance to a park-and-ride lot than to work. Both of these assumptions are used to determine the forecast VMT reduction. In general, the methods calculate the VMT reduction due to HOV facility implementation in three steps. The methods first calculate the VMT reduction due to trips eliminated by SOV to HOV shifts. The relationship used is as follows: Change in peak VMT due to trip changes = (change in peak work trips * average work trip distance). Next the methods calculate the VMT reduction due to changes in trip length. The general relationship used is: number of potential new HOV users that utilize the park and ride lot * (average work trip distance - new work trip distance[average distance to park and ride lot]). The total VMT reduction for the peak period is the sum of the preceding two steps. HPMS was used to estimate 1990 Houston area (Harris County) VMT. The 1990 VMT estimate was obtained from the Texas Department of Transportation (TxDOT). The 1990 VMT estimate is an input into both models.

A problem exists in attempting to validate the SANDAG and SAI methods using HPMS VMT data. The HPMS model is based on a fixed growth rate, whereas the SANDAG and SAI methods calculate a VMT reduction based on the number of commute and non-commute trips eliminated due to HOV lane use, average commute trip length, and average non-commute trip length. The results of the HPMS model and the SANDAG and SAI methods are not suitable for validation comparison; therefore, an analysis of the significance of the models' estimation

procedures is examined in lieu of a validation analysis. The significance reviewed consists of the usefulness of the methods' predictions versus the usefulness of the HPMS predictions when used for environmental decision making. The author compared the general HPMS VMT estimation procedure with the models' VMT estimation procedure to determine the significance of the forecast procedures when used for environmental planning purposes.

The HPMS was used to estimate Houston area (Harris County) VMT for 1994. VMT estimates are developed using the six automatic traffic recorder (ATR) stations and numerous temporary traffic recorder stations in Harris County. Harris County was chosen because the 1990 Houston HOV system operates almost entirely in the county. HPMS VMT estimates were obtained from TxDOT for 1990 and 1992. A previous TTI study estimated 1993 VMT using the 1990 and 1992 TxDOT data (17). The 1994 VMT estimates were developed from the TxDOT data and the TTI 1993 VMT estimates. The 1993 TxDOT HPMS data were not available at the time of the study. Both the 1990 and the 1994 VMT estimates were obtained using HPMS.

The total regional VMT for Harris County is made up of non-local and local VMT. Non-local VMT consists of trips which have either a beginning or an end outside the county. Local VMT consists of trips which both begin and end within the county. The Houston 1994 non-local VMT was projected using an average annual growth factor calculated based on the metropolitan area's network model traffic assignments. Local VMT was projected using an estimate of the 1994 population based on a linear growth curve, the official 1993 county population estimates, and the 1993 per capita VMT estimates. Non-local and local VMTs were calculated as follows (18).

$$\text{Non-local 1994 VMT} = \text{Non-local 1993 VMT} * (\text{Model 1996 VMT} / \text{Model 1990 VMT})^{1/2}$$

$$\text{Local 1994 VMT} = 1994 \text{ Population} * (\text{Local 1993 VMT} / 1993 \text{ Population})$$

Both non-local and local VMT were adjusted for summer weekday traffic using a summer adjustment factor and a weekday adjustment factor. Their sum is the total region VMT per day. The results of the VMT estimates are stated in Table 8.

Table 8
1994 HPMS VMT Estimate for Harris County

Descriptor	VMT Estimate
Non-local 1994 VMT	71,643,928
Local 1994 VMT	14,457,735
Total 1994 VMT	86,101,663

ANALYSIS PROCEDURE

Verification, Validation, and Calibration

Verification, validation, and calibration of transportation models are conducted to ensure that the models reproduce the real-world environment. Since calibration is rarely performed by the users, the default parameters provided by the designers are generally used without allowance for local variations. The adequacy of default parameters provided with transportation models is an increasing concern.

Verification is fairly straightforward and easier than validation and/or calibration and requires no real-world data. Verification is accomplished by comparing a model's documented logic with the computer codes. If they are similar, the model verification is successful. The only difficulty may occur due to inadequate documentation which details the model's logic and structure. In an environment of inadequate documentation, the task of verification becomes more challenging. If a model is organized in a component structure, then each component should be verified separately. However, as the components are put together, the model must be verified at each stage.

Unfortunately, validation and calibration of transportation models can be extremely difficult if not impossible to perform in some cases. Because a transportation system currently exists (the system being modeled), a comparison can be made to determine if the model results represent local conditions. However, supporting that the model performs with adequate accuracy

within its sphere of applicability could be an enormous task given the wide diversity in traffic characteristics and network complexities.

Furthermore, it is unclear as to how proposed models which represent mobile source emission reduction benefits can ever be validated with real-world data. No data collection system exists which gathers emission data for specific vehicles and their current operating modes. A proposed system would consist of black boxes installed in vehicles with global positioning system transceivers which transmit position, speed, and vehicle operating conditions to a central data processing system. Such a system would be expensive to implement and operate. An alternative is to validate and calibrate models which estimate mobile source emission benefits with traffic characteristic data. These types of data range from simple traffic counts to detailed vehicle trajectories collected over a duration of 15 minutes to several hours. Even though these types of data are obtainable, they are often unavailable or very expensive to collect. In order to spare expense, default parameters with known limitations are often used. The limitations are the lack of allowance for local variations and the absence of understanding of how the defaults were generated.

Model calibration of mobile source emission models is nearly impossible to accomplish with the current state of technology. Since instrumentation is not presently in place to measure mobile source emissions accurately, a paradox exists where the only method of calibrating a mobile source emissions model is with another mobile source emission model or estimation method. Without an accurate real-world data base in which to compare modeled mobile source emission results, there can be no true model calibration. In summary, since the real-world local situation is unknown and model calibration is based on varying model parameters to increase the models ability to mimic the local situation, calibration is not possible in the current environment.

In summary, the study consists of verification and validation of the SANDAG and SAI methods for determining mobile source emission reduction potentials of HOV facilities. Verification is accomplished by use of documentation which details the methods' logic and by comparing the documented logic with the computer codes. Since the task of using mobile source emission data for validation is arduous if not impossible, the author used computer model documentation and traffic characteristic data as the primary validation analysis tool. However, calibration of the models' mobile source emission forecast is not possible without emission data.

Analysis Methodology

The foundation methods, SAI and SANDAG, were analyzed for model verification and validation. The task focuses on the critical analysis of each method and is broken into five major components: (1) evaluation of procedural logic and assumptions within the methods, (2) model verification using existing documentation, (3) data evaluation requirements, (4) model validation using AVI speed data and trip change estimates by trip type, and (5) selection of a method for use in Texas. These components will examine the basis for each method's functionality. It is important to understand how each method processes its data to estimate emission benefits and to ensure that each method is properly coded into the computer. The data requirements for the methods are of equal importance. Extensive data requirements are not desirable to the user; however, insufficient data will not yield accurate estimates. Assumptions made in a methodology are critical to the models' performance. It is important that the assumptions be valid and reasonable.

The procedural logic was reviewed for organization and reason. Furthermore, a dimensional analysis of each step was performed to ensure the units were correct. Each model was evaluated step by step to ensure that the logic flow was correctly sequenced and to determine if the reasoning and assumptions of each step were adequate.

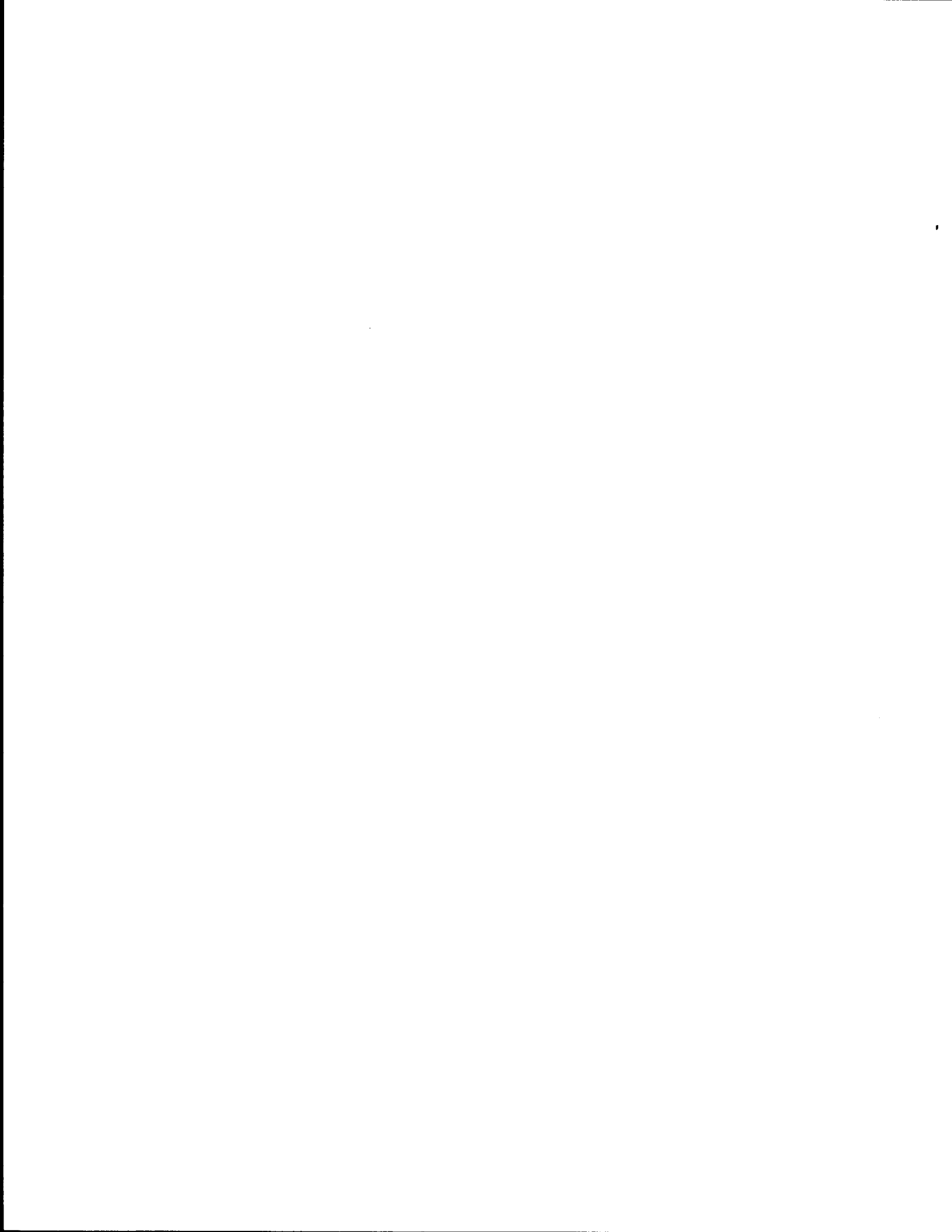
Model verification was accomplished by reviewing the translation of the conceptual model into a correctly working computer program. The documented logic was compared to the computer algorithms and checked for similarity. If overall similarity existed, then the model was verified. The SANDAG and SAI models were verified using the procedural logic listed in their user manuals (7,9).

The data requirements of the SANDAG and SAI methods were examined to determine which variables were difficult to quantify. These variables are important to identify in order to alert future researchers that extra effort may be required to define the variables.

The SANDAG and SAI methods were validated using traffic characteristic data and were run using the acquired 1990 traffic, travel behavior, demographic, and emissions data. The results were compared to 1994 AVI speed data for freeway main lanes and HOV lanes and trip experience of the Houston HOV system. The 1990 data and the 1994 data are the foundation of the validation study. Model validation was accomplished by comparing AVI speed data and

ongoing Houston HOV trip experience to the modeled speed increase and trip reduction output. The validation analysis was based on the difference between the modeled and AVI speeds plus the trip change estimates by trip purpose (work or non-work). If the modeled speed data and trip change trends are similar to current HOV experience then the model can be "roughly" validated and has potential use for Texas urban nonattainment areas. Finally, the VMT output was examined to determine its significance.

The results of the first four components of the critical analysis will determine if either model or a modification of either model is suitable for use in Texas. One of the methods or a modification of one of the methods will be selected and guidelines for use will be provided in Chapter V.



CHAPTER IV: RESULTS

The comparison and critical analysis of the SAI and SANDAG methods includes five components: (1) evaluation of procedural logic and assumptions within the methods, (2) model verification using existing documentation, (3) data evaluation requirements, (4) model validation using AVI speed data and trip change estimates by trip type, and (5) selection of a method for use in Texas. The focus of the analysis is the evaluation of the SANDAG and SAI methods procedural logic and the validation of the methods' using traffic characteristic data as the primary analysis tool.

PROCEDURAL LOGIC AND ASSUMPTIONS

Model Performance - SANDAG Methodology

The SANDAG transportation module consisting of ten steps first calculates the reduction in peak trips based on miles of freeway affected, average mode shift from drive alone per mile of HOV lane per hour, number of hours in peak period, and induced number of vehicle trips on mixed-flow lanes due to additional capacity. Three primary problems exist in the trip reduction estimation. "First, SANDAG's definition of a work trip varies from that of a traditional model trip. A home based work (HBW) trip in a traditional model is defined as a direct trip between home and work without any stops. SANDAG defines a HBW trip as a trip that begins at home and terminates at work and allows an intermediate stop" (8). This difference makes the SANDAG trip results difficult to compare or translate to traditional models. Second, indirect trip effects are not calculated by SANDAG. Indirect trip effects refer to additional trips that occur when a commuter leaves a vehicle home and another household member uses the vehicle for other purposes. Third, the induced number of vehicle trips on a mixed-flow lane due to additional capacity is a user specified value. The model's output is highly sensitive to the latent traffic demand because it determines the extent of trip reduction benefits due to HOV lane implementation. As the magnitude of latent travel demand increases, the magnitude of trip reduction benefits decrease in a one-to-one ratio. Since latent traffic demand is difficult to determine, it creates a serious problem for the analyst to resolve. If the analyst under-predicts latent travel demand then HOV trip reduction benefits are over-predicted and vice versa.

The SANDAG method calculates the reduction in off-peak trips as zero. HOV lanes are assumed to benefit peak-period commuters. Therefore, the reduction in total trips equals the reduction in peak-period trips. The trip reductions are determined by a formula based primarily on the magnitude of the SOV to HOV shift rate multiplied by the number of people trips on the affected freeways. In general, the computation consists of a participation rate times the potential number of participants to yield a reduction in person trips. The logic is straightforward; however, difficulties may arise in determining the participation rate.

Next, SANDAG calculates the reduction in peak and off-peak VMT from the reduction in peak and off-peak trips. Since the reduction in off-peak trips equals zero, the reduction in off-peak VMT equals zero. In general, the methods calculate the peak VMT reduction due to HOV facility implementation in three steps. The first step is to calculate the VMT reduction due to trips eliminated by SOV to HOV shifts. The relationship used is as follows: Change in peak VMT due to trip changes = (change in peak work trips * average work trip distance). Next, the method calculates the VMT reduction due to changes in trip length. The general relationship used is: Number of potential new HOV users that utilize the park-and-ride lot * (average work trip distance - new work trip distance[average distance to park-and-ride lot]). The total VMT reduction for the peak period is the sum of the preceding two steps. The general logic is adequate.

Finally, the speed change for the peak period is calculated based on the reduction of peak VMT, the total peak VMT before the reduction, and peak elasticity of speed with respect to volume. The SANDAG method calculates the change in regional speed using the following: Percentage change in peak speeds = -(reduction in peak VMT)/(total peak VMT)*(peak elasticity of speed with respect to volume). The logic is simplistic but adequate for aggregate analysis.

Changes in emissions are calculated by the emission module. The emission module utilizes the transportation module output and combines the output with emission factor data obtained from MOBILE5a to develop an estimate of baseline emissions and pollutant reductions for an HOV facility.

First, the emission changes are calculated from vehicle trip changes. The SANDAG method requires the same vehicle distribution as required by MOBILE5a. The first step is to calculate the cold-start and hot-start trip changes. The step requires two important inputs,

percentage of cold-start trips for work trips and percentage of cold-start trips for non-work trips. These percentages directly affect the emission reduction calculation. The SANDAG method provides these values. The model assumes that 100 percent of work trips will be cold-starts because the vehicle will have sufficient time to cool between trips to and from work. The percentage of cold-starts for non-work trips is assumed to be 43 percent, which is taken from a MOBILE4.4 default (8). The percentage of cold-starts for non-work trips is difficult to estimate.

Cold-start and hot-start emission factors are determined by subtracting the input stabilized emission factor from 100 percent of vehicles in cold-start conditions operating at 26 miles per hour and from 100 percent of vehicles in hot-start conditions operating at 26 miles per hour, respectively. The calculated emission factors are used to determine changes in emissions. The step has an important assumption: "the trip-start driving conditions are uniform and comparable to the trip-start driving conditions of the Federal Test Procedure driving cycle." The assumption was designed to simulate urban driving conditions, and the emission factors derived from MOBILE5a are based on this driving cycle (19).

The first step further evaluates the hot-soak and diurnal emissions associated with trip changes. Neither of these emission types is expected to produce significant emission reductions in relation to an HOV facility. Unfortunately, diurnal emissions increase when vehicle trips decrease; therefore, HOV facilities have the potential to increase diurnal emissions, but not significantly.

The second step in the emission module estimates emission changes associated with VMT changes. Hot stabilized emissions are calculated using the vehicle distribution. The emission factors are derived from the MOBILE5a output from the peak- and off-peak-period regional speeds prior to HOV facility implementation. VMT- related evaporative emissions are calculated next. Thus, total emission change associated with VMT changes equal the sum of these two emission categories.

The third step is to determine the emission changes associated with fleet speed changes. These emission changes are a result of improved traffic flow. The key assumption in this step is that all vehicles in the region are affected by an HOV facility, regardless if they travel on the HOV facility during the peak period or not. The assumption is based on the hypothesis that increased use of an HOV facility will decrease congestion and, thus, beneficially affect speeds

on other parts of the transportation network. CO is reduced more substantially than VOC and NOx in this step due to the sensitivity of CO to speed.

The final step sums the results of the first three steps to estimate total emission changes. The emission module is straightforward; however, the module is unable to evaluate modal emissions. Modal emissions involve vehicle acceleration, deceleration, cruise, and idle cycle. Numerous acceleration and deceleration changes in vehicle operation are known to increase fuel consumption and, thus, cause increases in vehicle emissions. This is because MOBILE5a was designed to estimate fleet emissions based on average speeds.

In summary, the procedural logic is simplistic and does not satisfactorily address such issues as indirect trip effects and latent travel demand. Furthermore, the SANDAG HBW trip differs from the traditional model work trip which creates difficulties in translating or comparing the model results to that of a traditional model which is more frequently used and accepted.

Model Performance - SAI Methodology

The SAI method's structure is similar to the SANDAG method with some exceptions. Its travel effects module consists of nine steps. The first step is to calculate the number of person trips affected. Dimensional analysis revealed that the units of the first step were vehicle trips, not person trips, as stated in the SAI documentation. The person trips affected had been transformed into vehicle trips by use of the average vehicle occupancy input. In order to follow the methodology procedural guidelines, the author modified the model and removed the Average Vehicle Occupancy (AVO) term from the equation to correct the units. The second step is a conversion from person trips affected to vehicle trips affected. Once again dimensional analysis revealed a flaw in the final units. The denominator of the equation was corrected by the author to yield the proper units, vehicle trips. This was accomplished by placing AVO in the denominator of the entire equation, not just a fraction of the equation. In order to continue the study, the author continued the analysis of the SAI model by using the modified SAI method.

Unlike the SANDAG method, the SAI method attempts to estimate indirect trip effects for work-related and non-work-related trips in its third step. However, like the SANDAG method, the SAI method assumes that only the peak period is affected; thus only the direct and indirect trip changes for peak work trips and peak non-work trips are calculated. SAI estimates

in work and non-work travel increases based on several variables including the work trip and the non-work trip generation rates for SOV users and the fraction of the population that does not own a vehicle. Dimensional analysis revealed that the units for this step were in person trips per household days.

Next SAI calculates the total trip changes due to HOV lane implementation. A reduction in total trip changes generally leads to improved roadway travel conditions. Since latent travel demand is the travel demand attracted to a roadway because of improved flow conditions, the method determines latent travel demand. Unfortunately, SAI calculates latent travel demand; but it does not use the results of its calculations in the methodology to assess travel demand impacts. SAI should have used the results to quantify the effects on HOV lanes. SAI calculates the reduction in peak trips by multiplying the magnitude of the SOV to HOV shift rate by the number of affected people trips on the facility. The logic is similar to SANDAG and contains the same difficulty, the determination of the shift rate.

The reduction in VMT is calculated by the sum of VMT associated with peak vehicle trip reductions and changes in trip length. The logic and methodology is comparable to the SANDAG method. The change in regional speed is determined from changes in VMT and elasticities. The calculation is identical to the SANDAG method's calculation of regional speed change. Changes in emissions are estimated from the travel changes. The SAI emission module is similar to the SANDAG module.

The overall logic of the method is sound but inconsistencies in Steps 1 and 2 are weaknesses. The logic of Steps 1 and 2 of the method failed dimensional analysis. Modifications by the author correct the dimensional analysis flaws of Steps 1 and 2 and make the SAI logic superior to the more simplistic SANDAG logic. The author continued the study using the modified SAI method in order for the evaluation to be worthwhile. From this point on the terms SAI and modified SAI are synonymous.

MODEL VERIFICATION

Overall, the verification of the SANDAG and SAI methods was satisfactory. The documented logic and the computer programs functioned similarly. Even though the SAI method had logic errors in Steps 1 and 2, it was correctly programmed according to documentation which

contained the logic errors. The SAI documentation was more intelligible than the SANDAG documentation which allowed more precise verification. The greater detail allowed the author to verify the SAI method with greater ease. The SANDAG documentation was vague in some areas, which introduced minor difficulties for the author to complete the verification. However, the difficulties were not significant enough to deter adequate verification of the SANDAG method.

THE DATA REQUIREMENTS

The SANDAG and SAI HOV methods of assessing the mobile source emission reduction potential of HOV facilities have several data requirements that are difficult to determine. Both methods require information about peak-period trips to determine HOV mobile source emission reduction potential. Peak-period modeling is required to determine these data; however, traditional planning models forecast 24-hour periods, not just the peak period. The best way to determine the peak-period data requirements is through household survey. HGAC had compiled most of the Houston household survey data which allowed examination of the peak-period travel.

Both models use variables called scope descriptors as required data entry. A scope descriptor is used to define HOV facility scope when implemented. Examples of scope descriptors are frequency of participation and number of participants with respect to the HOV TCM. The models also use HOV project descriptors that are similar to scope descriptors and function as supplemental inputs used to determine HOV effectiveness. An example of a HOV project descriptor is new work trip length. New work trip length is determined by the new length of the work trip resulting in HOV lane use. New work trip length was assumed to be the average distance to a park-and-ride lot. The assumption is based on a Houston traveler using bus transit or meeting a carpool or vanpool at the park-and-ride lot. The SAI methodology uses HOV scope descriptors more effectively than the SANDAG model. It is easier to use the SAI method to specify a target participation rate for a HOV facility with use of HOV scope descriptors. For example, in the SAI method the analyst can specify the fraction of potential trips who will use transit, whereas in the SANDAG method no such option exists.

Both methods use input variables that are difficult to determine for conducting model validation. The SANDAG variables are critical inputs into the method. The SAI variables are

primarily used to specify a target participation rates and have default values. Tables 9 and 10 list the difficult to determine data for the SANDAG and SAI methodologies respectively.

**Table 9
SANDAG Inputs That Are Difficult to Determine**

Variable
Induced number of vehicle trips on mixed flow lanes due to additional capacity
Average mode shift from drive alone per mile of HOV lane per hour

**Table 10
SAI Inputs That Are Difficult to Determine**

Variable
Fraction of potential trips that will use transit
Fraction of potential trips that will use rideshare
Fraction of potential trips that will use fringe parking
Fraction of new carpoolers who join existing carpools and don't meet at park-and-ride lot
Fraction of new carpoolers who join new carpools and don't meet at park-and-ride lot
Fraction of people who drive to the public transit station

MODEL VALIDATION

Model Validation Difficulties

The SANDAG and SAI methods require different input variables for assessing HOV mobile source emission reduction potential. For example, the SANDAG methodology requires the user to input the induced number of vehicle trips on mixed-flow lanes due to additional

capacity (latent travel demand), whereas SAI does not account for latent travel. Therefore, the variable was zeroed out in the SANDAG method in order to compare the models' results. When SANDAG and SAI variables were similar, the exact value was used in each model. Thus, the same elasticities, peak travel characteristics, and demographic data were used when similar. The use of non-similar variables increased the uncertainty of the validation comparison. If the modeled results were dissimilar, which was correct? It was difficult to determine the magnitude of an HOV's effect on mobile source emissions. The author determined that the ratio of the results could be compared since the methods' logic was similar. For example, if the SANDAG results yielded three times the reduction of work trips to non-work trips due to the implementation of an HOV facility, then the SAI model should yield the same ratio. This evaluation method allowed the author to analyze the methods without attempting to compensate for magnitude differences caused by the use of different input variables. The validation of the correctly modeled magnitude of speed, trip, and VMT changes is indeterminate without actual real-world data for comparison purposes. If the ratios are unequal, then the analysis becomes more difficult. The SANDAG and SAI model validation was accomplished with use of AVI main lane and HOV lane speed data; furthermore, the change in vehicle trips was used as validation data to determine if the model was succeeding in mimicking the real world. Also, the significance of the modeled VMT output is discussed.

Modeled Results

The SANDAG and SAI methods yielded the results shown in Table 11. Both SANDAG and SAI methods modeled peak-period work trip reductions to peak-period non-work trip reductions in the same ratio supporting the author's assumption. Magnitude differences do exist. The SAI method forecasted almost five times the reduction in total trip changes and in VMT but only about half the regional speed increase. The magnitude differences in trip changes and VMT are due to the differences in input variables.

**Table 11
SANDAG and SAI Travel Change Results**

SANDAG Travel Change Results			
Change	Peak Period	Off-Peak Period	Total
All Trips	-23,275 trips	0	-23,275 trips
Work Trips	-6,922 trips	N/A	-6,922 trips
Non-Work Trips	-16,353 trips	N/A	-16,353 trips
VMT	-218,863 vehicle miles	0	-218,863 vehicle miles
Speed	7.8%	0.0%	N/A
SAI Travel Change Results			
Change	Peak Period	Off-Peak Period	Total
All Trips	-99,120 trips	0	-99,120 trips
Work Trips	-31,093 trips	N/A	-31,093 trips
Non-Work Trips	-68,027 trips	N/A	-68,027 trips
VMT	-954,320 vehicle miles	-14,2465 miles	-968,565 vehicle miles
Speed	3.1%	0.0%	N/A

AVI Validation of Speed Increase

AVI data suggest that the speed increase for the freeway main lanes that directly correspond to an adjoining HOV facility from 1990 to 1994 is on the order of 20 percent. Table 6 shows the TTI-measured 1990 average peak-period speed on mixed-use freeway lanes to be 40.5 mph and on HOV lanes to be 57.2 mph. The mixed-use freeway lane average peak-period speed was measured on approximately 28 miles of Katy, North, and Northwest freeway sections with corresponding HOV facilities. The HOV lane speed corresponds to the average peak-period bus operating speeds on the Katy, North, and Northwest facilities. Since the 1990 HOV average

peak-period speeds are based on bus operating speeds, the data are probably conservative in nature because buses tend to travel in the main traffic stream. Mixed vehicle average peak-period speeds for the HOV facility were unavailable. Table 7 reveals AVI measurements of 1994 average peak-period mixed use freeway lane speeds and HOV lane speeds to be 48.8 mph (approximately a 20 percent increase from 1990) and 56.5 mph, respectively. Thus, the AVI data show that HOV lane speeds have demonstrated little or no change; but corresponding mixed use freeway lane speeds have increased dramatically. HOV peak-period person trips increased 16 percent from 1991 to 1992; and AVO increased slightly from 1.48 to 1.51 from 1990 to 1992, which may explain the speed increase of the mixed-use freeway lanes (20). Peak-period person trip magnitude data and AVO for 1993 and 1994 were unavailable at the time of the study. The SANDAG methodology estimated a regional speed increase of 7.8 percent, and the SAI methodology estimated a regional speed increase of 3.1 percent. The speed increases are assumed to affect the entire metropolitan region with an HOV system. Previous research by TTI has demonstrated that speed increases on the main lanes of an HOV facility have been as much as 50 percent due to the impact of HOV lanes (20). However, it is important to remember that the models estimate regional speed increases which encompass freeways, arterials, local streets, etc., rather than the speed increase of the mixed-use freeway lanes adjacent to an HOV facility. HOV facilities are only 8.4 percent of the freeway system, and the HOV benefits are assumed to occur only in the peak period. A conservative speed increase trend should be reflected by the models because, theoretically, a 50 percent increase on 8.4 percent of the freeway mixed-use vehicle lanes corresponds approximately to a 1 to 2 percent regional speed increase. Yet regional speed increases of 3.1 to 7.8 percent in the peak period were predicted by the methods. The methods overestimate the regional speed increase effect of HOV facility implementation.

In summary, the models both correctly assessed a regional speed increase trend; however, the accuracy of the magnitude of the regional speed increase is debatable. A 7.8 percent regional speed increase predicted by SANDAG is doubtful considering only 8.4 percent of the freeways in 1990 had HOV facilities. The 3.1 percent regional speed increase forecasted by the modified SAI method is more defensible but still an overestimation. The regional speed increase trend due to the implementation of an HOV facility is a function of the size of the HOV facility and the magnitude of the SOV to HOV ridership shift. The logic which estimates the more

conservative speed forecast is easier to support considering the percentage of freeway facilities with HOV lanes and the sensitivity of MOBILE5a to speed changes. MOBILE5a is very sensitive to speed inputs and if the regional speed changes are overestimated, the predicted emissions impact will be too liberal. Finally, the use of unfavorable data mitigates the results of the speed validation.

Validation of Trip Reductions

The SANDAG and SAI models forecast peak-period work trip reductions to peak-period non-work trip reductions in the same ratio; therefore, it was demonstrated that the models' logic was similar, but differences in input variables caused a magnitude difference in the results. Unfortunately, both models overpredicted peak-period non-work trip reductions (see Table 11). The SANDAG method estimated a reduction of 6,922 peak-period work trips and 16,353 peak-period non-work trips. The modified SAI method estimated a reduction of 31,093 peak-period work trips and 68,027 peak-period non-work trips. Thus, both models estimated that peak-period non-work trips would be reduced more than two-to-one over peak-period work trips per day. This result is illogical. The majority of Houston HOV users during the peak period are commuters (more than 90 percent) (20); furthermore, the majority (about 64 percent) of Houston peak-period trips are commute trips. It is difficult to understand why non-work trips would be reduced more than work trips, since the purpose of HOV facilities is to reduce peak-period congestion and is targeted at commuters. HOV benefits are gained through shifting SOV commuters to HOV commuters. There is a risk in the shift: indirect trip increases. Therefore, it is reasonable to believe HOV benefits are at greatest risk from indirect trip increases, and those trips are more likely to be of the non-work trip nature. HOV benefits are gained primarily through commuter benefits (work trips), not through non-commuter benefits. Both models fail to address this accurately.

Significance of Modeled VMT

The SANDAG and SAI methods estimate a daily VMT reduction of 218,863 and 968,565 vehicle miles, respectively. The HPMS model predicts a daily regional VMT value based on set expansion factors shown in Table 8; HPMS predicted a sizable increase in Harris County VMT.

The significance of the SANDAG and SAI VMT estimation method is that it isolates the impact of the HOV TCM, whereas the HPMS VMT estimation incorporates population and growth factors. Thus, the SANDAG and SAI methods do not account for factors other than the impact of the implementation of an HOV facility. Since the SANDAG and SAI methods do not account for other factors, the methods forecast a gross VMT reduction, not a net VMT reduction. The forecast format is appropriate for the air quality planning process because the process requires specific data on the benefits/disadvantages of HOV implementation. The data format is ideal for the economic and environmental decision making process that considers the implementation of HOV facilities in nonattainment areas. The transportation planner needs to know the benefits/disadvantages of HOV system implementation without consideration of other uncontrollable mitigating factors such as population or regional growth. However, since the methods do not account for other factors, the net benefit of the VMT reduction is unknown. Therefore, the predicted mobile source emission reductions may be overestimated.

Validation of Emissions

The emission module was set up to analyze the emission reductions for the ozone season (summer) since Houston is a nonattainment area for ozone. The SANDAG and SAI modeled emission benefits due to HOV facility implementation are shown in Tables 12 and 13, respectively. Both models predicted emission reductions in VOC, CO, and NOx.

**Table 12
SANDAG Ozone Season Emission Changes (kilograms/day)**

Pollutant	Trip Changes	VMT Changes	Fleet Speed Changes	Total
HC (VOC)	-96	-359	-4,491	-4,946
CO	-709	-3,697	-42,942	-47,349
NOx	-61	-477	361	-177

Table 13
SAI Ozone Season Emission Changes (kilograms/day)

Pollutant	Trip Changes	VMT Changes	Fleet Speed Changes	Total
HC (VOC)	-542	-1,584	-1,811	-3,937
CO	-3,925	-16,312	-17,279	-37,516
NO _x	-230	-2,110	118	-2,222

The emission results of both models are dependent upon speed. MOBILE5a is highly sensitive to speed and is the foundation of the models' emission modules. MOBILE5a calculates emission changes for the ozone season based on regional average peak-period and off-peak-period speeds adjusted by the modeled speed changes. The SANDAG model revealed the greatest emission reductions in VOC and CO due to the 7.8 percent speed increase and the lowest reduction for NO_x. NO_x emissions tend to increase as speed increases. The emission results are completely dependent on the travel module results of trip, VMT, and speed changes.

General Discussion of Results

The current practice of estimating the impacts of proposed transportation programs and projects based primarily on changes in vehicle speeds, VMT, vehicle trips, and vehicle mix is probably too simplistic for accurate predictions. More accurate predictions of the changes in the number of vehicle trips by trip purpose will improve the results since the methodologies do not adequately forecast trips by trip purpose for HOV lanes. Accurate travel survey data are the foundation for any future methodology.

Mobile source emission rates are sensitive to vehicle acceleration rates, the number of trips made, the length of the trip, the driving cycle, how long the vehicle has been parked since the previous trip, whether a vehicle is parked in a covered garage or in the sun, and refueling factors. EPA's MOBILE5a emission rate model is not sensitive to all of these factors. California's EMFAC7E emission rate model is, in some respects, an improvement; but it also has limitations that may lead to inaccurate predictions. The current emission rate models are designed around

average speeds. In order to improve estimation procedures, an emission rate model must be developed that more accurately predicts the driving cycle through use of mathematical distributions or a repeating "hill-climb" process. A mathematical distribution has great potential for use, especially if it is a known distribution such as the Normal or Erlang distribution. If a problem can be described by a mathematical distribution, it can be simplified with defined mathematical procedures. Finding the appropriate distribution is the difficult task. A "hill-climb" process involves the use of an iterative model with repeating cycles. Its solution is founded on a trial and error basis. Both estimation improvements are attempts to define the modal boundary conditions of a vehicle's operating cycle.

Most mobile source emission reduction strategies attempt to reduce the number of SOVs used for peak-period trips. Only the SAI model attempted to identify what happens to the vehicles that were previously used for work trips, or more specifically indirect trip effects. Do these vehicles remain parked? Are they now available for the spouse to use or the teenager to take to school and use after school? Anecdotal evidence collected from people whose work schedule is such that they have every other Friday off suggests that they travel further and make more trips on the off day than on a typical work day, even though the vehicle is probably not being used during the peak period (*I*). The mobile source emissions produced by the vehicle may be higher on the off day. The SANDAG model did not attempt to account for indirect trip effects.

Latent travel demand was calculated by SAI but not used in the methodology and is an input in the SANDAG model. Both models failed to accurately account for latent travel demand. Latent travel demand is difficult to estimate and to account for in a model. The research did not reveal any model which currently provides for latent travel demand in its methodology.

Both methodologies forecast peak-period non-work trip reductions to be twice the magnitude of peak-period work trip reductions. HOV facilities are designed to reduce peak-period work trips, not peak-period non-work trips. The SANDAG and SAI methods failed to recognize this fact. The majority of Houston peak-period trips are commute trips (approximately 64 percent). The vast majority of Houston peak-period HOV trips are commute trips (more than 90 percent). However, both models predicted that peak-period non-work trip reductions would

exceed peak-period work trip reductions due to the implementation of an HOV facility. The methodologies failed to forecast the primary purpose of HOV facilities.

The SAI methodology was more conservative in its estimation of regional speed increase due to HOV implementation than the SANDAG methodology. However, both speed increase estimations were greater than expected. Furthermore, the SANDAG speed estimate was greater than the SAI speed estimate even though the SAI methodology predicted five times greater the work trip and VMT reductions than SANDAG. The regional speed estimation is directly influenced by work trip and VMT predictions.

The advantage of the more conservative estimate is demonstrated by the air quality impact estimations. Both models use MOBILE5a which is highly sensitive to speed. A conservative estimate is better than a liberal estimate for air quality planning purposes because overestimating mobile source emission impacts of HOV facilities can skew the MPO's plan to improve air quality in the region. Finally, the conservative speed estimation logic is the better estimate because the model forecasts a regional speed increase using global parameters.

One of the primary assumptions is that both methods function using average values for estimating regional benefits (aggregate analysis). A single average value for an entire region is difficult to define or justify. The SANDAG and SAI methods are based on aggregate analysis which tends to oversimplify the problem. Thus, the models' results can be expected to be fair, at best, considering the level of precision involved.

Both models failed validation because trip changes by trip purpose due to implementing an HOV facility were dissimilar to real-world observations and expectations. The methods forecast peak-period non-work trip reductions to be more than twice that of peak-period work trip reductions. However, HOV facilities target reducing peak-period work trips. Houston HOV experience reveals that over 90 percent of HOV trips are work trips which implies that work trip reductions should exceed non-work trip reductions. Thus, the models failed to accurately forecast the observed local environment.

METHODOLOGY SELECTION

The results revealed that the SAI method has the greatest potential for future use. However, it requires modification before it can be used in Texas. The first of two major

modifications is changing the trip change reduction logic to more accurately reflect current HOV experience. Work trip reductions should exceed non-work trip reductions based on current HOV experience. Also, the speed change logic must be modified to a more conservative methodology. The current logic overestimates speed changes due to the implementation of a HOV facility, which in turn overestimates the emission reduction potential when using MOBILE5a as the emission factor model. A dampening factor is needed to more accurately represent the effect of speed changes due to the implementation of an HOV facility on the entire transportation network. Thus, a modified version of the SAI method will be presented for use in Texas in Chapter V of this report.

CHAPTER V CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The SANDAG and SAI models are at the forefront of current sketch planning tools used to determine mobile source emission impacts of HOV facility implementation. The importance of verification and validation of these methods cannot be understated in light of the passage of recent legislation requiring transportation professionals to consider the environmental impacts of transportation facilities. Furthermore, the economic impacts of determining the projected mobile source emission reduction potential of HOV facilities is an important consideration because the CMAQ program requires an air quality impact analysis before approving the obligation of CMAQ funds. Finally, the CAAA legislation structure will curtail economic development and community expansion by restricting construction of additional transportation facilities if National Ambient Air Quality Standards are not satisfied.

Procedural Logic and Assumptions

The SAI method contained errors in its first two logic steps which calculate total person trips affected and total vehicle trips affected. The errors were discovered using dimensional analysis. The units of the first two steps were incorrect. The author corrected the units in each step to complete the analysis. The corrected SAI logic was named the modified SAI method.

The SANDAG method, unlike the SAI method, failed to support indirect trip effects. Both methods failed to address latent travel demand issues accurately. The modified SAI method's logic was found to be superior to the SANDAG method's logic. The SAI method accounted for indirect trip effects and attempted to simulate latent travel demand but did not use the latent travel demand calculations. The modified SAI method has the greater potential for use in determining mobile source emission reduction potential of HOV facility implementation due to its superior logic.

Verification

Overall, the verification of the SANDAG and SAI methods was satisfactory; the documented logic and the computer programs functioned similarly. Even though the SAI method had logic errors in Steps 1 and 2, it was correctly programmed according to SAI documentation which contained the logic errors. The SAI documentation was more intelligible than the SANDAG documentation which allowed more precise verification and ease of verification. The SANDAG documentation was vague in some areas which introduced minor, but not significant, verification difficulties.

The Data Requirements

Both methods require information about peak-period trips in order to determine the mobile source emission reduction potential of HOV facility implementation. Peak-period modeling is required to determine these data; however, traditional transportation planning models forecast 24-hour periods, not just the peak period. The best way to obtain peak-period trip data is through household survey.

The SANDAG method requires latent travel demand as an input variable. For the validation analysis, latent travel demand was set to zero in the SANDAG method in order to assess the results against the modified SAI method which does not account for latent travel demand. Furthermore, it was discovered that it is easier to use the SAI method to specify a target participation rate for an HOV facility.

Tables 9 and 10 describe difficult-to-determine input variables for the SANDAG and SAI methods respectively. Default values were used in the validation study for most of the difficult-to-determine variables.

Validation

Model Validation Difficulties

The SANDAG and SAI methods require different input variables for assessing HOV lane mobile source emission reduction potential. The use of dissimilar variables increased the uncertainty of the validation comparison: if the modeled results were dissimilar, which was correct? It was difficult to determine the magnitude of the effect on mobile source emissions

an HOV facility would incur. The author determined that the ratio of the peak-period work and non-work trip reduction results could be compared since the methods' logic were similar. The hypothesis proved supportable; the ratios were similar. The validation of correctly modeled output magnitude was indeterminate with current data availability. The SANDAG and SAI model validation was accomplished using AVI main lane and HOV lane speed data. Furthermore, the change in vehicle trips was used to assess the model's success in mimicking the real world.

AVI Validation of Speed Increase

AVI data suggest that the speed increase for the freeway main lanes that directly correspond to an adjoining HOV facility from 1990 to 1994 is approximately 20 percent. Thus, the AVI data demonstrate that the HOV lane speeds have demonstrated little or no change; but corresponding mixed-use freeway lane speeds have increased. HOV peak-period person trips increased 16 percent from 1991 to 1992; and AVO increased slightly from 1.48 to 1.51 from 1990 to 1992, which may explain the speed increase on the mixed-use freeway lanes. The SANDAG methodology estimated a regional speed increase of 7.8 percent, and the SAI methodology estimated a regional speed increase of 3.1 percent. In summary, both models correctly assessed a regional speed increase trend; however, the accuracy of the magnitude of the regional speed increase is debatable. The more conservative speed forecast of the modified SAI method is easier to support considering the percentage of freeway facilities with HOV lanes (8.4 percent) and the sensitivity of MOBILE5a to speed changes, but it still is an overestimation. However, the speed validation results are mitigated by underlying assumptions in the validation procedure involving the use of speed data from the same HOV facility as both the base and after condition.

Validation of Trip Reductions

The SANDAG and SAI models forecast peak-period work trip reductions to peak-period non-work trip reductions in the same ratio; therefore, it was demonstrated that the models' logic was similar, but differences in input variables caused a magnitude difference in the results. Unfortunately, both models overpredicted peak-period non-work trip reductions. The models estimated that peak-period non-work trips would be reduced more than two-to-one over peak-

period work trips per day. This seems illogical since more than 90 percent of Houston HOV users during the peak period are commuters, and approximately 64 percent of Houston peak-period trips are commute trips. It is difficult to understand why non-work trips would be reduced more than work trips, since the purpose of HOV facilities is to reduce peak-period congestion and is targeted at commuters. HOV benefits are gained through shifting SOV commuters to HOV commuters. There is a risk in the shift: indirect trips increases. Therefore, it is reasonable to believe HOV benefits are at greatest risk from indirect trip increases, and those trips are more likely to be of the non-work trip nature. HOV benefits are gained primarily through commuter benefits (work trips), not through non-commuter benefits. Both models fail to correctly address trip reduction benefits by trip purpose accurately.

Significance of Modeled VMT

The significance of the SANDAG and SAI modeled VMT results is that they isolate the impact of implementing HOV facilities. This is advantageous in determining the impact of HOV facility implementation without concern for mitigating factors. However, since the methods do not account for population and growth factors, they develop gross estimations. The disadvantage of a gross rather than a net estimation is that potential benefits may be overestimated.

Validation of Emissions

The emission results of both models are highly dependent upon speed. MOBILE5a is sensitive to speed and is the foundation of the models' emission rate modules. MOBILE5a calculates emission rate changes for the ozone season based on regional average peak-period and off-peak-period speeds adjusted by the modeled speed changes. The SANDAG model revealed the greatest emission reductions in VOC and CO due to the 7.8 percent speed increase and the lowest reduction for NOx. NOx emissions tend to increase as speed increases. The emission results are completely dependent on the travel module results of trip, VMT, and speed changes. Since the trip reduction changes by trip purpose are inaccurate, it is perceived that the emission estimations of the models are inaccurate because work trip and non-work trip lengths vary significantly.

Summary

Both models failed validation because trip changes by trip purpose caused by the implementation of an HOV facility were dissimilar to real-world observations and expectations. The methods forecasted peak-period non-work trip reductions to be more than twice that of peak-period work trip reductions. Houston HOV experience reveals that over 90 percent of HOV trips are work trips; therefore, peak-period work trip reductions should exceed peak-period non-work trip reductions. Thus, the models failed to accurately forecast the observed local environment.

RECOMMENDATIONS

Recommended SAI Model Improvements

Both models predicted results which are unexpected from the implementation of an HOV facility. The number of peak-period non-work trip reductions exceeded the peak-period work trip reductions by two to one. Both models failed to accurately predict the changes in travel characteristics that are associated with HOV facilities. Neither the SAI or SANDAG methodology can be recommended for use in their present condition. The SAI model has greater potential for future use than the SANDAG model based on the SAI model's superior logic and conservative speed change methodology. However, modifications to the SAI model must take place before its use can be incorporated into conformity demonstrations for the TIP and metropolitan transportation plan.

In order to recommend use of the SAI methodology, the model must be modified to include the following:

1. The first step of the SAI methodology is to calculate the number of person trips affected. Dimensional analysis revealed that the units of the first step were vehicle trips, not person trips. The person trips affected had been transformed into vehicle trips by use of the AVO input. In order to follow the methodology procedural guidelines, the author recommends the removal of AVO to correct the units. The removal of AVO in the first step will result in units of person trips.
2. The second step is a conversion from person trips affected to vehicle trips affected. Once again dimensional analysis revealed a flaw in the final units. The units were undefinable as a whole. It is recommended that the denominator of the

equation be corrected to yield the proper units by dividing the entire equation by AVO, not just a fraction of the equation as defined by SAI. The modification will not only correct the units but also increase the logic.

3. A modification must be made in the logic that calculates the peak-period work trip and non-work trip weighting factors. The weighting factor should be based on trip survey HOV data, specifically the trip purpose of HOV users during the peak period. Since the primary mobile source emission benefits of HOV facilities are gained by reducing peak-period work vehicle trips, the model's trip reduction methodology should reflect HOV peak-period user trip purpose. Incorporating the trip purpose of HOV peak-period users into the SAI model will correct the faulty work trip to non-work trip reduction logic of the present model. The variable for analysis is identified as the fraction of HOV peak-period trips that are work trips and designated as ω .
4. The regional speed change estimation logic must be altered in order to produce more conservative speed estimates. Overestimating the regional speed increase due to an HOV facility implementation leads to an overestimation of mobile source emission reductions. A dampening factor must be introduced to resolve the problem. The dampening factor is the ratio of the peak-period HOV VMT to the total peak-period VMT. The dampening factor better accounts for the true speed change impact of an HOV system because it weights the effect of the HOV system to the total system.

Future Validation Studies

The difficulty in conducting a validation study on a methodology to assess the mobile source emission reduction potential of HOV facilities is considerable given the current state of technology and data availability. No system currently exists which measures mobile source emissions along an HOV corridor. Thus, HOV mobile source emission reduction model validation must be accomplished by other means. Traffic characteristic data have shown the greatest potential as a validation tool for this purpose. The current methodologies generate

emission reductions based on changes in traffic characteristics due to implementation of an HOV facility.

Traffic characteristics must be modeled in the peak period in order to determine the impacts of HOV facilities. HOV facilities are specifically designed to reduce peak-period congestion through reduction in work trips; this is accomplished by increasing vehicle occupancy. Traditional transportation models model 24-hour periods, not just the peak period; thus different information is required to model HOV impacts on mobile source emissions. However, some traditional models have been modified to model the peak period.

Travel surveys which target the peak period are critical in collecting the correct data to be used to validate HOV mobile source emission reduction potential models. The travel surveys must gather specific trip purpose information of each HOV user, their trip length, and the vehicle occupancy if traveling in a privately-owned vehicle. AVO for transit may be monitored by counters on transit vehicles or by transit vehicle ticket sales. This information will enhance predictions on trip changes by trip type and increase the accuracy of VMT reduction estimates. Whether the HOV commuter uses a park-and-ride lot must be determined. If not, information on whether the car left at home is being used must be surveyed. This information will improve the estimation of indirect trip effects. The survey must determine if the HOV user previously was an SOV traveler and why or what caused the shift to HOV. This information can be a powerful tool in predicting whether or not an individual is likely to shift modes from SOV to HOV. It is possible that a shift variable based on a congestion index could be created and used in predicting SOV to HOV shifts.

Corridor traffic volume and speed counts must be conducted periodically to further advance the information collection on SOV to HOV shifts. If collected traffic volume and speed data variances can show a shift from SOV to HOV, then a relationship may be developed that better estimates the phenomena by using a speed-volume relationship. An ideal data collection tool for this purpose is AVI. AVI has already demonstrated peak-period data collection capabilities. AVI can monitor both the main lane and HOV lane volume and speed data. This may help enhance the understanding of latent travel demand. The hypothesis is that by monitoring the fluctuation in HOV and SOV lane volumes and speeds, a relationship for latent

travel demand can be potentially developed by comparing the HOV and SOV volumes and vehicle occupancy.

GUIDELINES

The primary goal of this research is to develop a methodology to determine the mobile source emission impacts from the implementation of an HOV facility. The verification and validation of the SANDAG and SAI models indicated that the SAI method had the greatest potential for future use. The SAI method was modified and named the modified SAI method. The remainder of this report will give future users of the modified SAI method a set of operating guidelines. The guidelines are organized into four major sections: 1) potential data sources, 2) modified SAI method travel module, 3) modified SAI method emissions module, and 4) example output comparison.

Potential Data Sources

Because the modified SAI method has the greatest potential for future use, possible data sources for future analyses and validation of the model are listed in Tables 14, 15, and 16. Table 14 presents travel data requirements and example sources including new requirements since the model was modified to correct for HOV trips by trip purpose. Table 15 lists HOV TCM data needs and example sources. Table 16 lists census data requirements and sources. MOBILE5a emissions model data requirements can be obtained from the nonattainment area MPO. Texas MPOs regularly use MOBILE5a and should have the MOBILE5a setup readily available. Model defaults may be used in circumstances where data are unavailable or unreliable.

Table 14
Travel Data Used in Modified SAI HOV Methodology

Travel Data	Example Sources
Total person trips/day	MPO, travel surveys
Percent of work trips to total trips/day	MPO, travel surveys
Work trip generation rate for SOV users	MPO, travel surveys
Non-work trip generation rate for SOV users	MPO, travel surveys
Average work trip length (time, distance)	MPO, travel surveys
New work trip length (distance)	MPO, transit authority
Average non-work trip length (time, distance)	MPO, travel surveys
Daily out-of-pocket commute cost	MPO, transit authority
Total trips/day affected by speed increase	MPO, travel surveys
Total VMT in peak and off-peak periods	MPO
Fraction of work trip VMT that occurs in peak period	MPO
HOV peak-period VMT	MPO

Table 14 Continued

Travel Data	Example Sources
Elasticity of mode choice with respect to cost	MPO
Elasticity of peak speed with respect to volume	MPO
Elasticity of off-peak speed with respects to volume	MPO
Length of AM and PM peak periods in hours	MPO
Number of work and non-work trips/day/vehicle	MPO, travel surveys
Peak-period and off-peak-period speeds prior to HOV implementation	MPO, traffic surveys, TTI
Number of person trips on the affected freeway(s)	MPO
Peak-period work vehicle trips	MPO, travel surveys
Total peak-period vehicle trips	MPO, travel surveys
Fraction of HOV peak-period trips that are work trips	MPO, travel surveys

Table 15
HOV TCM Data Used in Modified SAI HOV Methodology

HOV TCM Data	Example Sources
Fraction of trips made via shared mode	MPO, transit authority
Average speed on mixed-use freeway lanes	MPO, AVI
Average speed on HOV lane(s)	MPO, AVI
Average vehicle occupancy	Texas Average Occupancy Model, MPO
Average number of people per carpool	MPO
HOV elasticity of speed with respect to volume	MPO
Fraction of potential trips that will use transit	Transit authority
Fraction of potential trips that will use rideshare	Transit authority
Fraction of potential trips that will use fringe parking	Transit authority
Fraction of new carpoolers who join existing carpools and don't meet at park-and-ride lots	Transit authority
Fraction of new carpoolers who join new carpool and don't meet at park-and-ride lots	Transit authority
Fraction of people who drive to the public transit station	Transit authority
Number of HOV user work and non-work person trips	MPO, Transit authority, travel survey

Table 16
Census Data Used in Modified SAI HOV Methodology

Census Data	Example Sources
Total regional population	Census, City and County Data Book 1988, Texas Almanac
Average household size	Census, City and County Data Book 1988, Texas Almanac
Regional hourly wage	Census, City and County Data Book 1988, Texas Almanac
Fraction of population that does not own a vehicle	Census
Fraction of population that is employed (16+ years)	Census, City and County Data Book 1988, Texas Almanac
Fraction of the population that is unemployed (16+ years)	Census, City and County Data Book 1988, Texas Almanac

Modified SAI Travel Modules

The primary source of this material was the SAI method users guide (9). The modified SAI methodology incorporates the changes suggested in the recommendations section of this report. This section is a step-by-step guide through the procedures required to determine the trip, VMT, and speed changes associated with the implementation of an HOV facility.

Step 1. Identify the potential direct trip effect and trip type affected

The first step is to calculate the potential number of trips affected by the implementation of a HOV facility. The equation is as follows:

$$[1] \quad PT = ([SPDn/SPDh] - 1) * USE$$

where:

PT	=	potential trip effect
SPDn	=	average speed on mixed-use freeway lanes
SPDh	=	average speed on HOV lane(s)
USE	=	number of people trips on the affected freeway(s)

Step 2. Calculate the direct trip reductions

The second step is to convert person trips to vehicle trips affected. The equation is as follows:

$$[2] \quad \Delta TripsD = \{[(-Tran+(NOLD*RD) +NEW*RD*((NCAR - 1)/NCAR)]/AVO\} * PT$$

where:

$\Delta TripsD$	=	total trip reduction for work and non-work trips
TRAN	=	fraction of affected participants who will use transit (fraction of PT)
NOLD	=	fraction of ridesharers who join existing carpools and don't drive to park-and-ride lots
RD	=	fraction of affected participants who will rideshare (fraction of PT)

NEW	=	fraction of ridesharers who will form new carpools and don't drive to park-and-ride lots
NCAR	=	average number of people per carpool
AVO	=	average vehicle occupancy
PT	=	potential trip effect

$$[3] \Delta\text{TripsD},w = \omega * \Delta\text{TripsD}$$

where:

$\Delta\text{TripsD},w$	=	direct work trip reduction
ω	=	fraction of direct trip effects assumed to be work related (fraction of HOV peak-period trips that are work trips)

$$[4] \Delta\text{TripsD},nw = (1 - \omega) * \Delta\text{TripsD}$$

where:

$\Delta\text{TripsD},nw$	=	direct non-work trip reduction
ω	=	fraction of direct trip effects assumed to be work related (fraction of HOV peak-period trips that are work trips)

Step 3. Calculate the indirect trip effects

The third step calculates potential indirect trip increases. The formulation is:

$$[5] \Delta\text{Trips}_i,w = \{(NV*SHR*(SIZE-1)*EMP*TGw)*(\Delta\text{TripsD},w /2)\}$$

where:

$\Delta\text{Trips}_i,w$	=	indirect work trip increases
NV	=	fraction of the population that does not own a vehicle
SHR	=	fraction of trips made via shared mode
SIZE	=	average household size
EMP	=	fraction of the population that is employed
TGw	=	work trip generation rate for SOV users

$\Delta\text{TripsD},w$ = direct work trip reduction

$$[6] \Delta\text{Tripsi},nw = \{(NV*SHR*(SIZE-1)*UNEMP*TGnw)*(\Delta\text{TripsD},nw / 2)$$

where:

$\Delta\text{Tripsi},nw$ = indirect non-work trip increases
NV = fraction of the population that does not own a vehicle
SHR = fraction of trips made via shared mode
SIZE = average household size
UNEMP = fraction of the population over 16 that is unemployed
TGnw = non-work trip generation rate for SOV users
 $\Delta\text{TripsD},nw$ = direct non-work trip reduction

Step 4. Calculate the total trip changes

This step calculates the total trip changes by summing the results of Steps 2 and 3. The methodology is as follows:

$$[7] \Delta\text{NETRP}w,p = \Delta\text{TripsD},w + \Delta\text{Tripsi},w$$

where:

$\Delta\text{NETRP}w,p$ = total work peak trip changes
 $\Delta\text{TripsD},w$ = direct work trip reduction
 $\Delta\text{Tripsi},w$ = indirect work trip increases

$$[8] \Delta\text{NETRP}nw,p = \Delta\text{TripsD},nw + \Delta\text{Tripsi},nw$$

where:

$\Delta\text{NETRP}nw,p$ = total non-work peak trip changes
 $\Delta\text{TripsD},nw$ = direct non-work trip reduction
 $\Delta\text{Tripsi},nw$ = indirect non-work trip increases

Step 5. Calculate the VMT changes due to trip changes

This step calculates the peak-period VMT changes due to trip reductions. The logic is as follows:

$$[9] \Delta VMT_p = (\Delta NETRP_{w,p} * DIST_w) - (\Delta NETRP_{nw,p} * DIST_{nw})$$

where:

ΔVMT_p = change in peak-period VMT due to trip reductions

$\Delta NETRP_{w,p}$ = total work peak trip changes

$DIST_w$ = average VMT per work trip

$\Delta NETRP_{nw,p}$ = total non-work peak trip changes

$DIST_{nw}$ = average VMT per non-work trip

Step 6. Calculate the VMT changes due to trip length changes

Step 6 calculates the VMT changes due to changes in trip length such as driving to a park-and-ride lot to utilize transit rather than commuting SOV to work. The methodology follows:

$$[10] \Delta VMT_{l,w} = \{TRAN * DRIVTRAN + RD * (1 - NOLD - NEW)\} * PT * \{DIST_w - DIST_{new}\}$$

where:

$\Delta VMT_{l,w}$ = VMT changes due to trip length changes

TRAN = fraction of affected participants who will use transit

DRIVTRAN = fraction of people who drive to public transit station

RD = fraction of participants who will use ride sharing

NOLD = fraction of ridesharers who join existing carpools and don't drive to park-and-ride lots

NEW = fraction of ridesharers who form new carpools and don't drive to park-and-ride lots

PT = number of potential trips reduced

$DIST_w$ = average VMT per work trip

$DIST_{new}$ = new work trip length (distance to park-and-ride lots)

Step 7. Determine the total VMT changes

This step calculates the total VMT changes by summing the results of Steps 5 and 6. The procedure is as follows:

$$[11] \quad \Delta \text{NETVMT}_p = \Delta \text{VMT}_p + \text{PK}_w * \Delta \text{VMT}_{l,w}$$

where:

ΔNETVMT_p	=	total change in net peak VMT
ΔVMT_p	=	the net change in peak-period VMT due to trip changes
PK_w	=	fraction of work VMT that occurs in the peak period
$\Delta \text{VMT}_{l,w}$	=	the net change in peak VMT due to trip length changes

$$[12] \quad \Delta \text{NETVMT}_{op} = \Delta \text{VMT}_{op} + (1 - \text{PK}_w) * \Delta \text{VMT}_{l,w}$$

where:

$\Delta \text{NETVMT}_{op}$	=	total change in net off-peak VMT
ΔVMT_{op}	=	the net change in off-peak period VMT due to trip changes
PK_w	=	fraction of work VMT that occurs in the peak period
$\Delta \text{VMT}_{l,w}$	=	the net change in peak VMT due to trip length changes

Step 8. Calculate speed changes

The change in speeds associated with the VMT decreases are calculated using elasticities of speed with respect to volume. The change in peak and off-peak speeds are calculated as follows:

$$[13] \quad \Delta \text{SPD}_p = \Delta \text{NETVMT}_p / \text{TOTVMT}_p * \text{VMThov},p / \text{TOTVMT}_p * \epsilon_p$$

where:

ΔSPD_p	=	the change in peak-period regional speed
ΔNETVMT_p	=	total change in net peak VMT
TOTVMT_p	=	total VMT in the peak period
VMThov,p	=	total VMT on HOV in the peak period
ϵ_p	=	elasticity of peak speed with respect to volume

$$[14] \Delta SPD_{op} = \Delta NETVMT_{op} / TOTVMT_{op} * VMThov,op / TOTVMT_{0p} * \epsilon_{op}$$

where:

ΔSPD_{op}	=	the change in off-peak-period regional speed
$\Delta NETVMT_{op}$	=	total change in net off-peak VMT
$TOTVMT_{op}$	=	total VMT in the off-peak period
$VMThov,p$	=	total VMT on HOV in the off-peak period
ϵ_{op}	=	elasticity of off-peak speed with respect to volume

The terms $VMThov,p / TOTVMT_p$ and $VMThov,op / TOTVMT_{0p}$ in equations [13] and [14], respectively, are speed dampening factors to yield a more conservative speed change estimate. The dampening factor yields a more accurate speed change prediction compared to the old method (without the dampening factor) because it accounts for the size of HOV VMT in the speed change estimation methodology.

Modified SAI Method Emissions Module

MOBILE5a emissions model data requirements can be obtained from the nonattainment area MPO. Texas MPOs regularly use MOBILE5a and should have the MOBILE5a setup readily available. The analyst need only obtain the setup and make appropriate modifications in order to facilitate the modified SAI methodology requirements. MOBILE5a must be run for speeds 10 mph to 50 mph at 0.1 mph increments. Next, MOBILE5a is run at 2.5 mph to simulate idling conditions. Finally, MOBILE5a is run three times at 26 mph to obtain 100 percent cold starts, 100 percent hot starts, and 100 percent hot stabilized emission factors. Table 18 defines the values for various vehicle states that must be used for specific fields in the MOBILE5a scenario record for the 26 mph runs. The variables are defined below:

PCCN	non-catalyst vehicle in cold-start mode
PCHC	catalyst-equipped vehicle in hot-start mode
PCCC	catalyst-equipped vehicle in cold-start mode

Table 17
Vehicle State Inputs for MOBILE5a Scenario Record

<i>Vehicle State</i>	<i>PCCN</i>	<i>PCHC</i>	<i>PCCC</i>
100% Cold Starts	100.	00.0	100.
100% Hot Starts	00.0	100.	00.0
100% Hot Stabilized Starts	00.0	00.0	00.0

Thus, MOBILE5a is run a total of 404 times, and the emissions factors by vehicle type are entered into the modified SAI model.

Emissions Analysis Methodology

Material included in this section is largely taken from the SAI method users guide (9). This section details the step-by-step procedure to determine the emission changes due to the implementation of an HOV facility. The emission changes are based on the results of the travel module outputs of trip changes, VMT changes, and speed changes.

The emission analysis methodology is broken down into four major steps according to changes in travel activity variables (trips, VMT, and speed). Emission categories influenced by trip changes are hot start and cold-start exhaust, hot soak, and diurnal emissions. The emission categories influenced by VMT changes are hot-stabilized exhaust, running loss, crankcase, and refueling emissions. Speed influences the following emission categories: hot-stabilized exhaust and running loss emissions. The four major steps of the methodology are:

1. emission analysis of trip changes
2. emission analysis of VMT changes
3. emission analysis of changes in regional speed
4. total emission change (summing of Steps 1, 2, and 3)

Step 1. Emission analysis of trip changes

Step 1 evaluates the emission changes due to trip changes. The fraction of affected trips by vehicle type is represented by the term $\gamma_{TRIP.vehclass}$.

$$[1] \Delta TRIP_{total} = \Delta NETRP_{w,p} + \Delta NETRP_{nw,p} + \Delta NETRP_{w,op} + \Delta NETRP_{nw,op}$$

where:

$\Delta TRIP_{total}$	=	total trip changes
$\Delta NETRP_{w,p}$	=	total work peak trip changes
$\Delta NETRP_{nw,p}$	=	total non-work peak trip changes
$\Delta NETRP_{w,op}$	=	total work off-peak trip changes
$\Delta NETRP_{nw,op}$	=	total non-work off-peak trip changes

Calculate Cold-Start and Hot-Start Trip Changes

$$[2] \Delta TRIP_{cst} = \gamma_{cst.w} * (\Delta NETRP_{w,p} + \Delta NETRP_{w,op}) + \gamma_{cst.nw} * (\Delta NETRP_{nw,p} + \Delta NETRP_{nw,op})$$

where:

$\Delta TRIP_{cst}$	=	total number of cold-start trip changes
$\gamma_{cst.w}$	=	number of work trips that involve cold start (typically assumed to be = 1.0)
$\gamma_{cst.nw}$	=	number of non-work trips that involve cold start
$\Delta NETRP_{w,p}$	=	total work peak trip changes
$\Delta NETRP_{nw,p}$	=	total non-work peak trip changes
$\Delta NETRP_{w,op}$	=	total work off-peak trip changes
$\Delta NETRP_{nw,op}$	=	total non-work off-peak trip changes

$$[3] \Delta TRIP_{hst} = (1 - \gamma_{cst.w}) * (\Delta NETRP_{w,p} + \Delta NETRP_{w,op}) + (1 - \gamma_{cst.nw}) * (\Delta NETRP_{nw,p} + \Delta NETRP_{nw,op})$$

where:

$\Delta TRIP_{hst}$	=	total number of hot-start trip changes
$\gamma_{cst.w}$	=	number of work trips that involve cold start

- $\gamma_{cst.nw}$ = number of non-work trips that involve cold start
- $\Delta_{NETRPw,p}$ = total work peak trip changes
- $\Delta_{NETRPnw,p}$ = total non-work peak trip changes
- $\Delta_{NETRPw,p}$ = total work off-peak trip changes
- $\Delta_{NETRPnw,p}$ = total non-work off-peak trip changes

Determine Cold-Start and Hot-Start Emission Factors

Cold-start and hot-start emission factors in grams per trip can be determined from the following equations using the MOBILE5a model:

[4] $CST = (EXH_{100\%CST.26MPH} - EXH_{100\%STB.26MPH}) * 3.59$

where:

- CST = cold-start emission factor in grams per trip (which needs to be determined for all three pollutants and all vehicle classes)
- $EXH_{100\%CST.26MPH}$ = MOBILE5a emission factor in grams per mile at 100 percent cold-start operating mode at 26 mph vehicle speed
- $EXH_{100\%STB.26MPH}$ = MOBILE5a emission factor in grams per mile at 100 percent hot-stabilized operating mode at 26 mph vehicle speed
- 3.59 = the federal test procedure (FTP) cycle trip-start miles per trip

[5] $HST = (EXH_{100\%HST.26MPH} - EXH_{100\%STB.26MPH}) * 3.59$

where:

- HST = hot-start emission factor in grams per trip (which needs to be determined for all three pollutants and all vehicle classes)
- $EXH_{100\%HST.26MPH}$ = MOBILE5a emission factor in grams per mile at 100 percent hot-start operating mode at 26 mph vehicle speed

EXH_{100%STB.26MPH} = MOBILE5a emission factor in grams per mile at 100 percent hot-stabilized operating mode at 26 mph vehicle speed

3.59 = the FTP cycle trip-start miles per trip

Determine the Cold-Start and Hot-Start Emission Changes

The cold-start and hot-start emission changes are determined by multiplying the trip changes by the emission factors for each of the exhaust pollutants (HC, CO, and NO_x) and for each of the vehicle classes.

$$[6] \Delta HC_{cst} = \sum(\Delta TRIP_{cst} * \gamma_{TRIP.vehclass} * CST_{vehclass.HC})$$

$$[7] \Delta HC_{hst} = \sum(\Delta TRIP_{hst} * \gamma_{TRIP.vehclass} * HST_{vehclass.HC})$$

$$[8] \Delta CO_{cst} = \sum(\Delta TRIP_{cst} * \gamma_{TRIP.vehclass} * CST_{vehclass.CO})$$

$$[9] \Delta CO_{hst} = \sum(\Delta TRIP_{hst} * \gamma_{TRIP.vehclass} * HST_{vehclass.CO})$$

$$[10] \Delta NO_x_{cst} = \sum(\Delta TRIP_{cst} * \gamma_{TRIP.vehclass} * CST_{vehclass.NO_x})$$

$$[11] \Delta NO_x_{hst} = \sum(\Delta TRIP_{hst} * \gamma_{TRIP.vehclass} * HST_{vehclass.NO_x})$$

where:

ΔHC_{cst}	=	the cold-start HC emission changes due to trip reductions
$\Delta TRIP_{cst}$	=	number of cold-start trip changes
$\gamma_{TRIP.vehclass}$	=	fraction of trips for particular vehicle class
CST	=	cold-start emission factors in grams per trip for each vehicle class and pollutant
ΔHC_{hst}	=	the hot-start HC emission changes due to trip reductions
$\Delta TRIP_{hst}$	=	number of hot-start trip changes
HST	=	hot-start emission factors in grams per trip for each vehicle class and pollutant

Determine Hot-Soak Emission Changes

Hot-soak emissions are the HC evaporative emissions associated with the end of a vehicle trip. The determination methodology follows:

$$[12] \Delta HChsk = \sum(\Delta TRIP_{total} * \gamma_{TRIP.vehclass} * HSK.vehicleclass)$$

where:

$\Delta HChsk$	=	change in hot soak emissions
$\Delta TRIP_{total}$	=	total trip changes
$\gamma_{TRIP.vehclass}$	=	fraction of trips for particular vehicle class
$HSK.vehicleclass$	=	hot-soak factor (grams per trip) for the subscribed vehicle class reported by MOBILE5a

Determine Diurnal Emission Changes

Diurnal HC emissions result from the daily temperature changes that a vehicle undergoes while it is not being used. The calculation method of diurnal HC emissions follow:

$$[13] \Delta HC_{dnl.w.vehclass} = 0.676 * (\Delta NETRP_{w,p} + \Delta NETRP_{w,op}) / TPD_w * \gamma_{TRIP.vehclass} * (WDI_{vehclass} - MDI_{vehclass})$$

$$[14] \Delta HC_{dnl.nw.vehclass} = 0.676 * (\Delta NETRP_{nw,p} + \Delta NETRP_{nw,op}) / TPD_{nw} * \gamma_{TRIP.vehclass} * (WDI_{vehclass} - MDI_{vehclass})$$

$$[15] \Delta HC_{dnl} = \sum(\Delta HC_{dnl.w.vehclass} + \Delta HC_{dnl.nw.vehclass})$$

where:

$\Delta HC_{dnl.w.vehclass}$	=	change in diurnal emissions for a particular vehicle type and work trips
0.676	=	assumption that 67.6 percent of unused vehicles experience multi-day diurnal emissions
$\Delta NETRP_{w,p}$	=	total work peak trip changes
$\Delta NETRP_{w,op}$	=	total work off-peak trip changes
TPD_w	=	number of work trips per vehicle commute day
$\gamma_{TRIP.vehclass}$	=	fraction of trips for particular vehicle class
$\Delta NETRP_{nw,p}$	=	total non-work peak trip changes
$\Delta NETRP_{nw,op}$	=	total non-work off-peak trip changes
$WDI_{vehclass}$	=	weighted diurnal emission factor for a particular vehicle class (grams per vehicle)

MDIvehclass	=	multi-day diurnal emission factor for a particular vehicle class (grams per vehicle)
$\Delta\text{HCdnl.nw.vehclass}$	=	change in diurnal emissions for a particular vehicle type and non-work trips
$\Delta\text{NETRPnw,p}$	=	total non-work peak trip changes
TPDw	=	number of non-work trips per vehicle commute day
ΔHCdnl	=	net diurnal emission change

Total Emission Changes Due to Trip Changes

The total emission changes due to trip changes is calculated by summing all the emission categories by pollutant type. The methodology for HC, CO, and NOx follow:

$$[16] \quad \Delta\text{HCtrip} = \Delta\text{HCcst} + \Delta\text{HChst} + \Delta\text{HChsk} + \Delta\text{HCdnl}$$

$$[17] \quad \Delta\text{COtrip} = \Delta\text{COcst} + \Delta\text{COhst}$$

$$[18] \quad \Delta\text{NOxtrip} = \Delta\text{NOxcst} + \Delta\text{NOxhst}$$

where:

ΔHCtrip	=	change in HC emissions due to trip changes
ΔCOtrip	=	change in CO emissions due to trip changes
$\Delta\text{NOxtrip}$	=	change in NOx emissions due to trip changes

Note: all other variables previously defined

Emission Analysis of VMT changes

The emission changes due to VMT changes are evaluated in this step. The emission categories influenced by VMT are hot-stabilized exhaust, running loss, crank case, and refueling emissions. The last three categories are combined into one category for the analysis. Running loss, crank case, and refueling emissions are designated as VMT evaporative emissions.

Determine Hot-Stabilized Exhaust Emission Changes

A major portion of total emission changes are from exhaust emission reductions due to reduced VMT resulting from fewer trips and reduced trip length. The methodology for calculating hot-stabilized exhaust emissions follows:

$$[1] \Delta HC_{stb,p} = \sum(\Delta NETVMT_p * \gamma_{VMT,vehclass} * STB_{vehclass,hc,p})$$

$$[2] \Delta HC_{stb,op} = \sum(\Delta NETVMT_{op} * \gamma_{VMT,vehclass} * STB_{vehclass,hc,op})$$

$$[3] \Delta CO_{stb,p} = \sum(\Delta NETVMT_p * \gamma_{VMT,vehclass} * STB_{vehclass,co,p})$$

$$[4] \Delta CO_{stb,op} = \sum(\Delta NETVMT_{op} * \gamma_{VMT,vehclass} * STB_{vehclass,co,op})$$

$$[5] \Delta NO_x_{stb,p} = \sum(\Delta NETVMT_p * \gamma_{VMT,vehclass} * STB_{vehclass,nox,p})$$

$$[6] \Delta NO_x_{stb,op} = \sum(\Delta NETVMT_{op} * \gamma_{VMT,vehclass} * STB_{vehclass,nox,op})$$

where:

$\Delta HC_{stb,p}$ = hot-stabilized HC emission changes during the peak period (p) or off peak period (op)

$\Delta NETVMT$ = change in total VMT in peak period (p) or off-peak period (op)

$\gamma_{VMT,vehclass}$ = fraction of VMT for a particular vehicle class

$STB_{vehclass,hc,p}$ = hot-stabilized exhaust emission factor for a particular vehicle class and the subscripted pollutant during the peak-period (grams per mile)

$\Delta CO_{stb,p}$ = hot-stabilized CO emission changes during the peak period (p) or off-peak period (op)

$\Delta NO_x_{stb,p}$ = hot-stabilized NO_x emission changes during the peak-period (p) or off-peak period (op)

Determine VMT-Related Evaporative Emissions

The VMT-related evaporative emissions consist of the VMT-dependent, non-exhaust categories of running loss, crankcase, and refueling emissions. Running loss and crankcase emissions occur while the vehicle is in operation and, therefore, are affected by any change in VMT. Running loss and crankcase emissions have units of grams per mile. Refueling emissions

occur during refueling operations and utilized units of grams per mile. The peak-period VMT-related evaporative emission changes are calculated as follows:

$$[7] \Delta HC_{vevp,p} = \sum(\Delta NETVMT_p * \gamma_{VMT.vehclass} * VEVP.vehclass)$$

$$[8] \Delta HC_{vevp,op} = \sum(\Delta NETVMT_{op} * \gamma_{VMT.vehclass} * VEVP.vehclass)$$

where:

- $\Delta HC_{vevp,p}$ = VMT-related evaporative emission changes in the peak period (p) or off-peak period (op)
- $\Delta NETVMT$ = change in total VMT in peak period (p) or off-peak period (p)
- $\gamma_{VMT.vehclass}$ = fraction of VMT for a particular vehicle class
- $VEVP.vehclass$ = VMT-related evaporative emission factor for a particular vehicle class

Total Emission Changes Due to VMT Changes

Summing the emission changes of the hot-stabilized and running evaporative emission categories into one net emission change yields the total emission changes due to VMT changes. The following equations show the method of determining the total emission changes for HC, CO, and NOx.

$$[9] \Delta HC_{vmt} = \Delta HC_{stb,p} + \Delta HC_{stb,op} + \Delta HC_{vevp,p} + \Delta HC_{vevp,op}$$

$$[10] \Delta CO_{vmt} = \Delta CO_{stb,p} + \Delta CO_{stb,op}$$

$$[11] \Delta NOx_{vmt} = \Delta NOx_{stb,p} + \Delta NOx_{stb,op}$$

where:

- ΔHC_{vmt} = total HC emission changes due to VMT changes
- $\Delta HC_{stb,p}$ = hot-stabilized HC emission changes during the peak period (p) or off-peak period (op)
- $\Delta HC_{vevp,p}$ = VMT-related evaporative emission changes in the peak period (p) or off-peak period (op)
- ΔCO_{vmt} = total CO emission changes due to VMT changes

$\Delta\text{CO}_{\text{stb,p}}$	=	hot-stabilized CO emission changes during the peak period (p) or off-peak period (op)
$\Delta\text{NOx}_{\text{vmt}}$	=	total NOx emission changes due to VMT changes
$\Delta\text{NOx}_{\text{stb,p}}$	=	hot-stabilized HC emission changes during the peak period (p) or off-peak period (op)

Emission Analysis of Fleet Speed Changes

This step evaluates emissions changes due to changes in fleet vehicle speeds due to the implementation of an HOV facility. The emission categories affected by fleet vehicle speeds are hot-stabilized exhaust and running loss emissions. This step varies from the first two because all vehicle classes are affected by speed changes. The methodology formulas follow:

Determination of TCM Speeds

The base speeds of the region are known; thus, the HOV TCM speeds can be determined by:

$$[1] \text{ SPEED}_{\text{p,hov}} = \text{SPEED}_{\text{p,base}} + \Delta\text{SPD}_{\text{p}}$$

$$[2] \text{ SPEED}_{\text{op,hov}} = \text{SPEED}_{\text{op,base}} + \Delta\text{SPD}_{\text{op}}$$

where:

$\text{SPEED}_{\text{p,hov}}$	=	peak-period speed after HOV implementation
$\text{SPEED}_{\text{p,base}}$	=	peak-period speed prior to HOV implementation
$\Delta\text{SPD}_{\text{p}}$	=	change in peak-period speed
$\text{SPEED}_{\text{op,hov}}$	=	off-peak-period speed after HOV implementation
$\text{SPEED}_{\text{op,base}}$	=	off-peak-period speed prior to HOV implementation
$\Delta\text{SPD}_{\text{op}}$	=	change in off-peak period speed

Determination of TCM VMT

The effect of HOV facility implementation on VMT can be determined by the following:

$$[3] \text{ VMT}_{p,hov} = \text{VMT}_p + \Delta\text{VMT}_p$$

$$[4] \text{ VMT}_{op,hov} = \text{VMT}_{op} + \Delta\text{VMT}_{op}$$

where:

$\text{VMT}_{p,hov}$ = total peak-period VMT for modeling region after HOV implementation

VMT_p = peak-period VMT prior to HOV implementation

ΔVMT_p = change in peak-period VMT due to HOV implementation

$\text{VMT}_{op,hov}$ = total off-peak-period VMT for modeling region after HOV implementation

VMT_{op} = off-peak-period VMT prior to HOV implementation

ΔVMT_{op} = change in off-peak-period VMT due to HOV implementation

Emission Changes Due to Changes in Regional Speed

The emission change due to the change in regional speed is determined from the difference in emission factors evaluated at the speed prior to HOV implementation and at the speed after HOV implementation. The emission categories evaluated are hot-stabilized exhaust and running loss. The net emission change methodology due to an overall peak-period fleet speed change follows:

$$[5] \Delta\text{HC}_{spd,p} = \text{VMThov},p * (\text{STBflt}.hc.p.hov + \text{RNLflt}.p.hov) - \text{VMThov},p * (\text{STBflt}.hc.p.base + \text{RNLflt}.p.base)$$

$$[6] \Delta\text{HC}_{spd,op} = \text{VMThov},op * (\text{STBflt}.hc.op.hov + \text{RNLflt}.op.hov) - \text{VMThov},op * (\text{STB}.hc.op.base + \text{RNLflt}.op.base)$$

$$[7] \Delta\text{CO}_{spd,p} = \text{VMThov},p * (\text{STBflt}.co.p.hov - \text{STBflt}.co.p.base)$$

$$[8] \Delta\text{CO}_{spd,op} = \text{VMThov},op * (\text{STBflt}.co.op.hov - \text{STBflt}.co.op.base)$$

$$[9] \Delta\text{NOx}_{spd,p} = \text{VMThov},p * (\text{STBflt}.nox.p.hov - \text{STBflt}.nox.p.base)$$

$$[10] \Delta\text{NOx}_{spd,op} = \text{VMThov},op * (\text{STBflt}.nox.op.hov - \text{STBflt}.nox.op.base)$$

where:

$\Delta\text{HC}_{spd,p}$ = HC emission change due to peak-period speed change

VMThov,p	=	total peak-period VMT for modeling region after HOV implementation
STBflt.hc.p.hov	=	hot-stabilized emission factor for particular vehicle, pollutant, peak (p) or off-peak (op) period, and after HOV implementation (hov) or before HOV implementation (base)
RNLflt.p.hov	=	running loss emission factor for particular vehicle, pollutant, peak (p) or off-peak (op) period, and after HOV implementation
$\Delta\text{HCspd,op}$	=	HC emission change due to off-peak-period speed change
$\Delta\text{COspd,p}$	=	CO emission change due to peak-period speed change
$\Delta\text{COspd,op}$	=	CO emission change due to off-peak-period speed change
$\Delta\text{NOxspd,p}$	=	NOx emission change due to peak-period speed change
$\Delta\text{NOxspd,op}$	=	NOx emission change due to off-peak-period speed change

Total Emission Changes Due to Regional Speed Changes

The total emission changes due to regional speed changes for each pollutant, HC, CO, and NOx, are calculated by summing the peak and off-peak emission changes as follows:

$$[11] \Delta\text{HCspd} = \Delta\text{HCspd,p} + \Delta\text{HCspd,op}$$

$$[12] \Delta\text{COspd} = \Delta\text{COspd,p} + \Delta\text{COspd,op}$$

$$[13] \Delta\text{NOxspd} = \Delta\text{NOxspd,p} + \Delta\text{NOxspd,op}$$

where:

$$\Delta\text{HCspd} = \text{total HC emission changes due to change in regional speed}$$

$$\Delta\text{COspd} = \text{total CO emission changes due to change in regional speed}$$

$$\Delta\text{NOxspd} = \text{total NOx emission changes due to change in regional speed}$$

Note: All other variables previously defined

Determination of Total Emission Changes Due to HOV Implementation

The final step is to sum the emission changes from Steps 1 through 3 to yield the total emission changes due to the implementation of an HOV facility. The total emission changes can be calculated as follows:

$$[1] \Delta\text{HC} = \Delta\text{HC}_{\text{trip}} + \Delta\text{HC}_{\text{vmt}} + \Delta\text{HC}_{\text{spd}}$$

$$[2] \Delta\text{CO} = \Delta\text{CO}_{\text{trip}} + \Delta\text{CO}_{\text{vmt}} + \Delta\text{CO}_{\text{spd}}$$

$$[3] \Delta\text{NO}_x = \Delta\text{CO}_{\text{trip}} + \Delta\text{CO}_{\text{vmt}} + \Delta\text{CO}_{\text{spd}}$$

where:

ΔHC = final HC emission changes due to HOV implementation

ΔCO = final CO emission changes due to HOV implementation

ΔNO_x = final NO_x emission changes due to HOV implementation

Example Output Comparison

An example output of the modified SAI method is presented for comparison purposes. The same data provided earlier for the Houston HOV system were used. Thus, a direct comparison between the outputs of the different methods is possible. Table 18 shows the travel change results and Table 19 shows the ozone season emission change results. To compare the modified SAI method to the SAI method, refer to Tables 11 and 13. Table 11 is the SAI method travel change results, and Table 13 is the SAI method ozone season emission change results. As shown, the modified SAI method predicts that peak-period work trip reductions greatly exceed the peak-period non-work trip reductions. This more accurately reflects the Houston HOV experience. Furthermore, the more conservative speed change methodology of the modified SAI method produced a speed change of 1.4 percent rather than the 3.1 percent speed change predicted by the SAI method. The more conservative speed change methodology produced a great reduction in the predicted emission changes from fleet speed changes. However, the emission changes due to VMT changes increased because of the modification in Step 2 of the travel module. The modification incorporated the fraction of peak-period HOV work trips into the model's logic. Since Houston HOV peak-period trip experience primarily consists of work

trips rather than non-work trips and work trips are longer than non-work trips, the modification increased emission changes due to VMT reduction. This mitigated the effects of the reduction in emissions from the new speed change logic. In summary, the overall emission changes of both methods were similar but weighted differently due to the modifications. The modified SAI method more correctly estimates the changes in trip types, VMT, and speed changes; and the similarity in overall modeled results is due to random.

**Table 18
Modified SAI Method Travel Change Results**

Change	Peak Period	Off-Peak Period	Total
All Trips	-93,870 trips	0	-93,870 trips
Work Trips	-96,533 trips	N/A	-96,533 trips
Non-Work Trips	-5,081 trips	N/A	-5,081 trips
VMT	-1,291,139 vehicle miles	-28,019 vehicle miles	-1,319,158 vehicle miles
Speed	1.7%	0.0%	N/A

**Table 19
Modified SAI Ozone Season Emission Changes (kilograms/day)**

Pollutant	Trip Changes	VMT Changes	Fleet Speed Changes	Total
HC (VOC)	-533	-2,155	-819	-3,702
CO	-5,226	-22,186	-7,766	-35,177
NOx	-250	-2,875	39	-3,085

The modified SAI method shows that VMT changes have the greatest impact in reducing emissions rather than regional speed changes as in the SAI method. This is the result of the modifications to peak HOV trip type by trip purpose and the speed methodology.

Methodology

The previous sections outlined the basic procedures that are required to use the modified SAI method. The details of the logic were given to aid in the understanding of how the results were obtained. Determining mobile source emission impacts of HOV facilities is a complicated problem which varies from one system to the next. One of the biggest tasks involves collecting the required data; the data requirements are extremely intense. The next step is to run MOBILE5a for the designated study area and season of interest (ozone or carbon monoxide) as described to determine the emission factors for the region. The last step is to run the model and interpret the results. This is the most difficult task. The magnitude of mobile source emission impacts of a HOV facility are hard to verify. It is important to review the results of the travel module and to ensure the results are logical for the given data. The emission module is fairly straightforward and is based on the results of the travel module. Therefore, the travel module results are the critical results.

The modifications to the SAI method improved trip change expectations and made the speed change methodology more conservative. This resulted in a more accurate reflection of expected travel changes; furthermore, it yielded a more conservative speed estimate which translates to a more conservative emission estimate. It must be remembered that the method is a sketch-planning tool which utilizes aggregate analysis. The method yields predictions based on regional averages, and this fact must weigh heavily in the interpretation of the results.

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