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Analyze the Impact of Traffic on Air Quality and Select Appropriate ITS Strategies for Emissions Mitigation

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Research Report SWUTC/04/167829-1

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ABSTRACT

This report presents a framework for analyzing the air quality impact of transportation sector and selecting appropriate Intelligent Transportation Systems (ITS) strategies to reduce mobile source emissions. First within a GIS framework, the mobile source emissions are estimated on the basis of vehicle fleet composition, emission factors and traffic characteristics. Then, a concise four-step method is proposed to select ITS strategies to reduce traffic emissions according to the Federal Highway Administration (FHWA) ITS planning process version 2.1. Following the four-step method, the appropriate ITS strategies can be identified and their potential benefits and impact can be evaluated. In this study, the emission problems are defined based on the emissions modeling within a GIS framework. The ITS strategies are screened under the guidance of the National ITS Architecture. The identified ITS strategies are evaluated by doing experiments with ITS Deployment Analysis System (IDAS). A case study was performed in Austin, TX. It shows that the proposed emissions modeling method and the ITS strategy selection method is very helpful for regional ITS planning and evaluation. The methods and results from this report will be very useful for decision-makings in ITS investments and deployments.

EXECUTIVE SUMMARY

Transportation activities are significantly contributing to rising levels of air pollution in virtually every metropolitan area, and will continue to worsen as car ownership and travel demand continue to grow. Metropolitan areas with unacceptable air quality levels must develop strategies for reducing air pollution to meet the EPA air quality standards. Typical emission mitigation strategies include fuel improvement, adoption of new transportation alternatives such as hybrid vehicles, traffic control measures, travel demand management, and so on. As one of the emerging traffic control measures, the intelligent transportation systems (ITS) deployments are playing important roles in reducing mobile emissions. To develop measures of effectiveness and subsequent predictions of the overall impact of ITS strategies on air quality, an appropriate method is required to model the relationships between certain traffic characteristics and their resulting emissions.

This report targets on two goals: 1) develop a framework to analyze the impacts of the transportation sector on air quality, and 2) develop a method to select appropriate ITS strategies to manage mobile source emissions. First, based on a review of the state-of-the-art of mobile emission modeling and nationwide ITS implementations, a geographic information system (GIS) model is proposed to analyze the mobile emission levels in a certain metropolitan area. Within the GIS framework, the mobile source emission levels are estimated according to the vehicle fleet composition, emission factors and traffic characteristics. The EPA Mobile 6 model is applied in this study to estimate the emission rates. A case study is presented to demonstrate the emission analysis procedure. Following the Federal Highway Administration (FHWA) ITS planning process version 2.1, a concise four-step method is proposed to identify the ITS strategies that can reduce mobile emissions. The ITS strategies are screened under the guidance of the National ITS Architecture and the potential benefits of the identified ITS strategies are evaluated by performing experiments with ITS Deployment Analysis System (IDAS). A case study was performed to demonstrate the method. The results indicate that by incorporating the National ITS Architecture and IDAS, the FHWA ITS Planning Process is applicable to the regional ITS planning and is helpful for decision-makings on ITS investments and deployments in air quality control.

Following the method proposed by this study, it is determined that the market packages of incident management system, regional traffic control, environmental hazard sensing, integrated transportation management/route guidance, and broadcast traveler information are cost-effective ITS strategies to reduce mobile emissions. The incident management system, regional traffic control and environmental hazard sensing are recommended for deployments with the highest priority. The integrated transportation management/route guidance and broadcast traveler information packages are recommended for deployments as well, but with lower priority. The method can be extended to analysis on developing ITS strategies to improve safety, mobility, and other transportation improvement goals.

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Transportation activities are contributing significantly to air pollution in virtually most of metropolitan areas, which is becoming a serious problem and will continue to worsen as the car ownership and travel demand keep growing. According to the Federal Clean Air Act, as amended in 1990, any area that violates the national ambient air quality standards for any of the six criteria pollutants as few times as once per year and as often as four times over a three-year period is classified as a "nonattainment" area.

Carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbon (HC) emissions are the major emission products of transportation activities in urban area. Batchman et al. (2000) have mentioned that the estimation for the amount of pollutants produced by automobiles range from 33% to 97% of CO, 33% to 50% of NOx, 40% to 50% of HC, 50% of ozone precursors, and at least one-fourth of volatile organic compounds (VOC) (Chatterjee et al., 1997; SCAQMD, 1996; USEPA, 1995; CARB, 1994; USDOT, 1993).

Nonattainment areas for ozone, carbon monoxide, and PM10 are classified according to the severity of their air pollution. If a nonattainment area fails to comply with air pollution standards by a specified deadline, the EPA may extend the deadline but impose more stringent requirements to meet the standards. In 1997, for example, the EPA rejected Dallas-Fort Worth's bid for an extension to comply with the deadlines set for "moderate" ozone nonattainment areas, and instead reclassified the area as a "serious" ozone nonattainment area due to lack of progress on meeting the ozone standard. (Loftis et al., 1997). In addition, if there is a failure to develop a proper state implementation plan or a failure to implement the plan, the EPA may develop a federal implementation plan for the area and may impose sanctions for noncompliance, including the loss of federal highway construction funds, bans or stiffer limits on further industrial expansion, and the loss of federal Air Pollution Control Program grant funds.

The metropolitan areas with unacceptable air quality, i.e. nonattainment areas, have to develop strategies for reducing air pollution. To develop measures of effectiveness and subsequent predictions of the overall impact of air quality control strategies, an appropriate method is required to model the relationships between the traffic characteristics and their resulting emissions. Besides, models that incorporate these relationships must balance input data availability and quality with predictive power (Bachman et al., 2000).

1.2 GEOGRAPHIC INFORMATION SYSTEM

Geographic Information System (GIS) is a computer program capable of assembling, storing, manipulating, and displaying geographically referenced information (i.e. spatial data).

Generally, a Geographic Information System could be defined as a set of principles and techniques employed to achieve one (or both) of the following objectives:

- Finding suitable locations that have the relevant attributes. For example, finding a suitable location where an airport, a commercial forest or a retail outlet can be established. This is usually achieved through the use of Boolean (logical) operations.
- Querying the geographical attributes of a specified location. For example, examining the roads in a particular locality, to check road density or find the shortest path, and so on. This is often achieved by ‘clicking’ onto the location or object of interest, and examining the contents of the database for that location or object.

What distinguishes GIS from other forms of information systems, such as databases and spreadsheets, is that GIS deals with spatial information. GIS has the capability to relate layers of data for the same points in space, combining, analyzing and, finally, mapping out the results. Spatial information uses location as its reference base within a coordinate system. The most common representation of spatial information is a map on which the location of any point could be given using latitude and longitude, or local grid references such as the National Grid.

GIS data are usually stored in more than one layer in order to overcome the technical problems caused by handling very large amounts of information at once. It is easier to work with complex spatial problems one layer at a time, to enable the revision of the data without having to overhaul the entire information system. This is a fundamental aspect of GIS, and working with layers of geographical information is known as data integration. Spatial data may be represented in GIS in one (or both) of the two following formats:

- Vector model, as geometric objects: points, lines, polygons;
- Raster model, as image files composed of grid-cells known as pixels.

1.3 TRANSPORTATION CONTROL MEASURES

Transportation control measures (TMC) are transportation projects and related activities that are designed to achieve on-road mobile source emission reductions and are included as control measures in the State Implementation Plan (SIP). Examples include intersection improvements, signal improvements, High Occupancy Vehicle (HOV) lanes, Intelligent Transportation Systems (ITS), freeway corridor management, park and ride lots, travel demand management, pedestrian/bike facilities, rail, and carpool.

These strategies are designed to improve the operating efficiency of existing transportation system by encouraging use of alternative modes, altering trip patterns, and improving traffic flow. Basically, they belong to two categories: demand-side strategies and supply-side strategies. The objective of demand-side strategies is to increase vehicle occupancy, increase public transit usage, reduce the need to travel during peak hour periods, and reduce the travel demand on the transportation network (Strickland and Berman, 1995). On the other hand, supply-side strategies focus on increasing the capacity of existing transportation network so that the traffic low can be improved.

To increase the capacity of transportation system, there are different ways. Building more roads or expanding existing roads is the simplest and most straightforward option. However, in most large metropolitan areas, this option is not very feasible because the available land for new infrastructure is usually limited and is very expensive. Also, construction of new highway infrastructure could bring environmental risks because new infrastructure always makes it easier to pollute than to avoid pollution. Another option is to encourage the use of public transit and increase the vehicle occupancy by supplying HOV lanes. Besides, improving the efficiency of existing infrastructure is a very promising option. Intelligent Transportation Systems, which have great potential to improve the efficiency of existing transportation system, can be a good strategy for emission reduction.

1.4 INTELLIGENT TRANSPORTATION SYSTEM

Intelligent Transportation Systems (ITS) are varieties of technological advances that are improving the interfaces between drivers, roads and vehicles. These advanced technologies applied to ITS consist of information processing and management, telecommunication, electronic technologies, navigation technologies and other advanced technologies. In particular, these technologies and operations needed for a transportation system will satisfy the requirements of travelers on roads. Although there is not a standard definition, ITS can be named as the application of current and evolving technology to transportation systems and the careful integration of system functions to provide more efficient and effective solutions to multimodal transportation problems (Stockton et al., 1998).

Since the 1990s, ITS has become one of the most promising approaches to solving today's surface transportation problems. The original impetus for ITS deployments came from increasing concerns on congestion, highway accidents, mobile emissions, and limited public funding for construction of new infrastructures. In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) was passed by the U.S. Congress. Since then, the deployments of ITS have been greatly encouraged. Many states, especially those that received ITS model deployment initiative (MDI) funding from the federal government, have developed significant and integrated metropolitan transportation management systems in the early years of ITS (ITS America, 2002).

ITS has been employed to make commercial vehicle operations and public transportation system more efficient. ITS can be used to help manage arterial traffic, freeways, and incidents. By improving the traffic flow, the amount of mobile emissions can be reduced under a certain level of travel demand. According to the evaluations for these deployments, there were both successes and failures in these early years of ITS practices, with significant lessons learned from both types of experiences (Hauser et al., 2001). By synthesizing previous studies, the Joint Program Office (JPO) of the Federal Highway Administration (FHWA) suggested six good measures for ITS benefits evaluation (Mitretek Systems Inc, 1999, pp.16-17), which are the benefits ITS could bring to the transportation system:

- "Mobility", which indicates the capability of ITS to increase the average speed of vehicles in the transportation network.
- "Safety", which shows the change of accident rate after ITS is deployed.
- "Efficiency", which represents the capability of ITS in optimizing the efficiency of existing facilities.
- "Productivity", which shows the helpfulness of ITS in reducing operating costs and improving productivity.
- "Energy and Environment", which indicates the impact of ITS in saving energy and reducing emissions.

- “Customer Satisfaction”, which reflects the degree to which transportation consumers are accommodated by ITS service.

Understanding the goals behind these measures of effectiveness is helpful to understand the benefits ITS can generate. Particularly, in this study, in order to measure the impacts of ITS projects on the environment and energy usage, emission levels and fuel usage is commonly used. Emission levels are typically quantified by the contents of CO, NOx and HC in emissions.

1.5 OBJECTIVES AND STRUCTURE OF REPORT

The overall objectives of this study are: First, a GIS framework for mobile emissions analysis will be developed. Then, based on the GIS model, ITS solutions for mobile emission reduction will be proposed and their effectiveness and benefits will be examined. Finally, the ITS implementation plan will be recommended based on the alternative analysis results. A case study was performed in Austin, TX.

This report contains a literature review, a GIS application for emissions modeling, a framework for selecting ITS strategies to mitigate emissions, and the final conclusion and recommendations.

CHAPTER 2. LITERATURE REVIEW

2.1 INTRODUCTION

When considering modeling mobile emissions with Geographic Information System (GIS) and planning Intelligent Transportation System (ITS) strategies for air quality improvement, there are many considerations need to be accounted for in the assessment and decision making process. In order to better understand these considerations, the past studies in modeling mobile emissions with GIS, ITS planning and benefits evaluation will be reviewed and synthesized in this chapter. For better organization, this chapter will be broken down into two main parts: the literature of modeling mobile emissions with GIS and the studies in ITS planning and evaluation for reducing emissions.

2.2 MODELING MOBILE EMISSIONS WITHIN GIS ENVIRONMENT

Throughout the years there have been many different aspects of emission modeling and Geographic Information System framework for mobile emission prediction.

The application of GIS for modeling mobile emissions requires the mobile source emission prediction models. As we know, the travel demand has significant impacts on the mobile emissions. Stopher et al. (1996) did a series experiments on the use of travel forecasting procedures to examine the impacts of desegregation on estimates of mobile emissions. Six scenarios and several factors that have impacts on the travel demand were examined. The authors used MOBILE 5a model to generate emissions rates and predict the emissions. Current mobile source emission prediction models used by state and federal agencies include Environmental Protection Agency's (EPA) MOBILE and California Air Resources Board's EMFAC model. MOBILE5a is an older vision of MOBILE series models. MOBILE6.0 is a newest mobile source emission factor model developed and published by EPA (2002) for mobile emissions prediction. It is a software package that can provide predictions of current and future emissions from on road traffic. MOBILE6.0 is capable of analyzing three criteria pollutants, which are hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen (NOx). This model can calculate emission rates under different conditions affecting in-use emission levels as specified by the modeler to address a wide variety of air pollution modeling needs. Many studies have been done to estimate the emissions with the emission factors. For example, Mensink et al. (2000) developed an urban transport emission model for the Antwep area, Belgium. The model can be used to estimate hourly emissions of main pollutants such as CA, NOx, VOC, SO2 for individual streets and road segments. The emissions factors used in this study are derived from COPERT-II methodology (Ahlvik et al., 1997), which is similar to EPA MOBILE models.

The emission factors models have been widely applied. However, these models sometimes are often inadequate for analyzing the emissions impact of various transportation control measures, Intelligent Transportation Systems, alternative fuel vehicles and more sophisticated inspection/maintenance programs in many state air quality management plans. Barth et al. (1996) developed a physical approach for modal emissions modeling. In this study, the authors presents a new modal-emission modeling approach which is deterministic and based on analytical functions that describe the physical phenomena associated with vehicle operation and emissions productions. In the physical model, the emissions process is broken down into components that correspond to physical phenomena associated with vehicle operations and emissions productions. According to the author, the model relies on highly time-resolved emissions and vehicle operation data. The data should be collected from a wide range of vehicles of various emission control technologies. As we know, the emissions and fuel consumptions vary at different levels of road congestions. A set of facility-specific driving cycles are introduced to the EPA's MOBILE model. These cycles represent driving patterns for different types of facilities such as freeways and arterials. Barth et al. (1999) also used a state-of-the-art comprehensive modal emissions model to predict the integrated emissions and fuel use values for these cycles for a wide variety of vehicle-technology categories. It is found that mild speed perturbations at high speeds can lead to significantly higher emissions compared with the steady-state values.

In middle 1980s, GIS was introduced to transportation analysis. The first widespread of GIS in transportation research management was seen at that time. One major area of GIS application is transportation planning. With GIS, the traditional transportation planning process can be greatly refined. Miemeier et al. (1993) compare the difference between the transportation planning process within GIS environment and non-GIS planning process. The authors point out that the GIS model shows more advantages in land use analysis and travel demand analysis. However, the difference of traffic volume estimation results between the GIS model and manual model is not very significant. In a study performed by Johnston et al. (2000), the authors discuss how to link integrated urban models and geographic information systems. The study tries to solve the land use allocation problem within the GIS framework for policy assessment. GIS shows its advantages in land allocation modeling and produces detailed land use maps, which can also be used for environmental impact analysis. With the development of computer technology and software development, GIS plays a more and more important role in transportation applications. Simkowitz (1988) talked about the roles of GIS in transportation applications. With GIS, the data base can be integrated so that it is easy to use the same data across applications as well as associate diverse data sets previously unavailable for joint analysis. Since the activities of vehicles in the transportation system and resulting emissions are correlated with specific points in time and space, GIS is suitable for modeling the mobile source emissions. Thrill (2000) discusses the concept of GIS in a broader perspective of research in GIS. The author emphasizes the application requirements of GIS in transportation area and some challenges, which include the data management system, data interoperability, real time transport GIS, large dataset and distributed computing in GIS data management.

Introduced in the 1980s, the applications of GIS in mobile emissions modeling became populous in the middle 1990s. Fedra (1999) explored the relationship of the emissions monitoring, urban environment management modeling and GIS. According to the author, urban environment management must integrate the spatial, structural features of a city, typically captured in GIS, and the dynamics of environmental quality indicators that can be obtained by monitoring. The strategies for integrating monitoring, GIS and modeling are discussed in this paper, which is to use a common client-server architecture, an object-oriented design, embedded expert systems technology, and multi-media user interface to support easy access and easy use. The system is capable of environmental forecasting, environmental impact analysis, and traffic air quality analysis. Bachman et al. (1996) proposed a Geographic Information System framework for modeling mobile source emissions. In that study, the authors builds a conceptual framework of mobile emissions research model by integrating vehicle characteristics, vehicle activities and emission rates to estimate emissions for both on-network and off-network vehicle activities. Emissions from all kinds of vehicle activities are aggregated into grid cells in GIS. The spatial variability of emission concentration levels are displayed with hard-copy GIS maps to help decision makers and public understand the research findings. The authors indicate that the major limitation of this GIS model is the intensive data required. Souleyrette et al. (1991)

undertook a transportation-related air quality study in the Las Vegas metropolitan area. ARC/INFO is used to determine the compliance for Carbon monoxide and PM-10. This study focuses on the relationship of CO concentration levels with the vehicle miles traveled, gas station locations, and wind patterns. The authors use the regress analysis to explain the relationship between air quality levels and vehicle miles traveled or gas station locations. Hallmark et al. (1996) also tried to integrate GIS for transportation and air quality analysis. TransCAD 2.1 is used in this study as a transportation GIS tool. CALINE3 and CAL3QHC are used in this study as the air quality analysis models. The authors perform the impact evaluation of the land use plan and increasing pollution sources. Hot-spot analysis, contour overlay, and point-in-polygon analysis are conducted in this study. According to the authors, using GIS for air quality analysis is complicated because of model incompatibilities. On the other hand, CAL3QHC air quality model does not calculate the vehicle delay and total emissions generated at intersections. The authors indicate that although there are difficulties, integrating GIS and air quality analysis models offers several advantages compared to the traditional air quality analysis. Lin et al. (2002) performed another application of GIS to air quality analysis. The authors utilize a GIS framework that integrates a vehicle emission model, pollutant dispersion model, backward trajectory model and related database to estimate the emissions and spatial distribution of traffic pollutants in Taichung, Taiwan. The model in this study can be used not only for analyzing current mobile emissions situations, but also for the predictions of emissions influenced by changes in specific traffic conditions or management policies. The CO, NOx, SOx and TSP emissions generated by different types of facilities are estimated. The results of this study show that the visualization and analytical features of GIS provide more information and convenience to users, which also makes the model more efficient and flexible. Bachman et al. (2000) gave a summary of applying GIS to emissions analysis based on their study cooperated with EPA. The capability of GIS for mobile source emissions analysis has been proved. The framework proposed by the authors is very logical, although it requires a large amount of data. In a study performed by Rebolj et al. (1999), the authors integrated the existing emission calculation software with a graphic user interface to provide decision makers with updated emission information in an easily understandable form. Lindley et al. (1999) generated and applied an emission model within a GIS framework. The air quality analysis procedure of this study is similar to the study performed by Bachman et al. (1996). However, the authors spend more efforts in examining the uncertainty and comparing the results derived from different data alternatives. According to the authors, the estimation of the combustion-related emissions can be predicted with highest confidence. The uncertainties, including the treatment of evaporative emission sources, do not show significant impacts on the use of the method for basic air quality management activities.

GIS has also been applied to analyze the human exposure to air pollution. Jensen et al. (2001) applied GIS to develop a decision support tool for management of urban air quality and human exposures. This system, which is named AirGIS, is developed based on the Danish operational street pollution model, technical and cadastral digital maps, and Danish national database on buildings, cadastres and populations. The GIS tool enables mapping of traffic emissions, air quality levels and human exposures at residence address, work place and in streets. Moreover, this model enables the impact assessment of traffic air pollution. Kuosa et al. (2002) developed a mathematical model for assessing the population exposure to ambient air pollution in an urban area. In this paper, the authors evaluate the spatial and temporal variation of average exposure of urban population to ambient air pollution. By utilizing the results of traffic flows and emissions, emissions originates from stationary sources, and atmospheric dispersion of pollution, a model was developed to combine the predicted pollutant concentrations, people's activity information and location of population. GIS was used to analyze and visualize the human exposure to air pollution. This model is good for assessing the environmental impacts of transportation planning and land use scenarios.

Some other interesting studies which link air quality analysis and GIS include a framework developed by Marquez et al. (1999). This paper describes an attempt to integrate land use, transport and airshed models for evaluating the effect city form on air quality. The framework identifies the relationship between various components such as the GIS database, the land use-transport-environment module and the airshed model. The GIS/database components represent all mechanisms for managing data required by the other four components, including access to and conversion of input data, storage of intermediate and output data, provisions for report writing, charting mapping and other analytical representations of data. Briggs et al. (2000) introduced a regression-based method for mapping traffic –related air pollution. This paper evaluates the use of a GIS-based, regression mapping technique to model spatial patterns of traffic-related air pollution. Schmidt et al. (1998) introduced an integrated simulation system for mobile source emissions estimation. Since the emissions are mainly calculated through traffic counting combined with various statistical methods, the results are often inaccurate and do not reflect the dynamic characteristics of traffic flow. Therefore, the authors perform the emission simulation as well as scenario analysis by means of model based on simulation system. A SIMTRAP model is developed, which consists of two core components: one is the air pollution model DYMOS, the other is the dynamic traffic simulation model DYNEMO. Basically, the authors aim to calculate the emission based on the dynamic traffic simulation and visualize the simulation results with a local 3D GIS system. This study were not completed yet when this paper was published. Another interesting study is using GIS for transportation improvement site selection, which is performed by Nyerges et al. (1997). According to the authors, some transportation decision makings are collaborative in nature and geographically based. This paper takes the transportation improvement program as a site evaluation and selection problem. With the use of multi-criteria decision models integrated with GIS and group supported system (GSS), that problem can be addressed. The authors show very deep insight to the transportation improvement program evaluation and site selection problems.

Generally, in the studies for air quality analysis, the common characteristics exist in that the emission factors are widely applied to estimate the main pollutants and GIS plays a very important role in visualizing the results and manipulating the database. The capability of managing and manipulating database makes GIS a very powerful tool for air quality analysis. On the other hand, GIS can visualize the results with maps, which provides the decision makers a more understandable form. With these features, GIS is a very good tool for regional air quality analysis.

2.3 EVALUATION AND PLANNING OF ITS STRATEGIES FOR EMISSIONS MITIGATION

There are many ways to manage the transportation system to reduce the mobile source emissions. One of them is transportation demand management. However, many transportation professionals and those people who implement the transportation demand management program have been frustrated by the inadequate quantitative information on what types of transportation demand management strategies work best and where to implement those strategies. To find a method to quantify the impact of transportation demand management program, Schreffler et al.

(1996) developed a standardized methodology and then applied it to 15 transportation demand management demonstration projects. The uniqueness of this method lies in that it accounts for those switched from High Occupancy Vehicle (HOV) mode to another and for those who accessed the new commuter alternative by driving alone to a pick-up point by give a discount to the vehicle trip reduction. This method also uses the standardized emission factors to calculate reductions in pollutants such as CO, NOx, reactive organic gases, and fine particle matter. The transportation demand management programs examined in this study include single commute alternative, multiple commute options, home telecommunicating or teleconferencing, and satellite work centers. In a study did by Euritt et al. (1996), four strategies are constructed and examined to address the emission issue in Texas. Among these strategies, the transportation control measures (TCM) are considered. However, the main focuses of the authors are some policy scenarios such as pricing strategies and accelerated vehicle retirement. The impacts of transportation control measures on emissions and energy consumption are not discussed in detail in this study.

Since 1990s, the Intelligent Transportation Systems (ITS) has been considered as a potential strategy to reduce the negative impacts associated with the motor vehicle traffic. The original impetus for deployments of ITS came from increasing public concerns on congestion, safety, environment, and limited funding for construction of new infrastructure. Many states, especially those that received ITS model deployment initiative (MDI) funding from the federal government, have developed significant and integrated metropolitan transportation management systems in the early years of ITS (ITS America, 2002). According to the evaluations for these deployments, there were both successes and failures in these early years of ITS practices, with significant lessons learned from both types of experiences (Hauser et al., 2001).

It is generally accepted that ITS bring benefits to the real world. As we know, the deployments of ITS components have potential impacts on the following aspects: ITS can affect the traffic flow along the specific links of transportation network; ITS have impacts on the number of trips (vehicle or person) by mode and time-of-day along the specific links or road segments; ITS can change the travel cost for specific origin and destination (O-D) pairings. These aspects are highly interrelated with most of the factors that characterize the traveler's behavior and the performance of a transportation system. By enhancing the efficiency of the transportation system, ITS can lead to capacity improvements with the same physical infrastructure. Some valuable studies have been conducted to compare the cost-effectiveness of building new roads and ITS. According to the results of an ITS benefits study (USDOT, 1997) and a cost-effectiveness study of ITS Versus New Roads (McGurrin et al., 1997), a 20-year life-cycle cost analysis for fifty major urban areas for the two options (capacity increase by building new roads and by deploying ITS) indicates that the ITS-based investment would "reduce the need for new roads while saving approximately 35% of the required investment in urban highways" (McGurrin et al., 1997). So, it can be seen that the impacts of ITS will finally in turn affect the emissions and fuel consumptions, which may determine the air quality of a city or area. According to US EPA, Energy and Transportation Section Division, Office of Policy (1998), a methodology for evaluating the emissions and fuel consumption effects of ITS must address all potential deployment outcomes, including the potential for induced travel effects. Although progress has been made in developing new travel demand, traffic simulation, and emissions models, more efforts must be put to accurately assess the short and long-term emissions and fuel consumption impacts of ITS.

In ITS benefits evaluations and reviews, "energy and environment" is recommended by the Joint Program Office of Federal Highway Administration as a good measure to assess ITS projects along with some other measures like safety, mobility, efficiency, productivity, and customer satisfaction. Environmental benefits are very important considerations in ITS benefits evaluations, especially for those ITS applications designed for non-attainment areas. However, to evaluate the air quality impacts of ITS, in most cases, it can only be estimated by some analysis tool and simulation software because the data cannot be collected if the ITS projects are not deployed. Many studies have been conducted to evaluate the ITS benefits. These studies include the simulation experiments as well as field tests. According to the review by Mitretek Systems Inc (1999), the impact of ITS on the environment and energy, which is basically on the air quality and fuel consumption, has been tested. Small-scale studies generally show positive impacts on the environment. For example, the evaluation results of TransGuide system in San Antonio, TX show that the incident management system can reduce duel consumption up to 2600 gal/major accident, which in turn reduced the mobile source emissions. Another example is the Electronic Toll Collection (ETC) system in Florida. The ETC in Florida results in 7.3% of CO reduction, 7.2% of HC reduction, and 34% increase of NOx increase with 40% ETC usage.

The SmartTraveler system in Boston shows an estimated 1.5% of NOx reduction and 33% of CO reduction.

Presently, there are not many tools available on market for ITS impact evaluation, especially for environmental benefits analysis. Boxill et al. (2000) reviewed and compared several traffic simulation models for supporting ITS development. The authors evaluate the simulation models through two steps: initial screening and in-depth evaluation. According to the evaluation, the authors recommend that currently CORSIM and INTEGRATION seem to have the highest probability of success in real-world applications. The authors also mention that the AIMSUN 2 and PARAMICS models will be brought to the forefront in the near future for use with ITS applications after more calibration and validation. During the review of relevant studies, it is noticed that some special software packages, for instance, the ITS deployment Analysis System (IDAS) and Screening Intelligent Transportation Systems (SCRITS) have been developed to assist the ITS impact assessment. However, they are not included in Boxill's review.

To develop ITS plans for regional areas, one method is to develop an ITS strategic plan using the ITS planning procedure suggested by the Federal Highway Administration (FHWA) in the National ITS Architecture. One example is a case study using the National ITS Architecture to develop an Intelligent Transportation Systems strategic plan for a medium-sized area (Sadek et al., 2001). In this study, the authors follow the guidance of the National ITS Architecture. A market package screening procedure was developed. The National ITS Architecture proved to be very useful and applicable through this case study. However, according to the researchers, there is a limitation in this method: this approach is suitable only for developing an ITS strategic plan, but not for recommending specific ITS projects while the regional and state agencies want the tools or methods that suggest the specific deployment plan of ITS.

Another method for ITS planning is the multiobjective decision analysis. The planning of Intelligent Transportation Systems is notable for multiple goals and for multiple constituencies (Teng et al., 1996). Therefore, it is feasible to apply multiobjective decision analysis in ITS evaluation and planning. An example is a multicriteria method for transportation investment planning (Giuliano, 1985). In this study, concordance analysis is employed for identifying the best compromise alternatives. Multiple weighting schemes are generated to balance the scores of different criteria. With this method, the best compromise solution can be identified. However, three factors affect the results significantly. One factor is that different problem formulations may result in different conclusions. The second factor is that the assignments of weights to the criteria may have significant impact on the final results. The third factor is the measurement errors which may lead to wrong conclusions. According to the author, there are two limitations for this approach: one limitation is that the bias of measurements for the criteria has significant impact on the results. The other limitation is that the optimal solution may not exist because of the various weighting schemes. Another example is a multiattribute analysis of goals for ITS planning (Levine et al., 1996). In this study, the authors consider the stakeholder valuation of broad goals. A modified Analytical Hierarchy Process (AHP) is developed. The author derives the preference weights from survey results. Furthermore, inter- and intra-group comparisons are made by the authors. This method is proved suitable for policy and system design. However, there are two limitations in this study: one limitation is the underscored relative importance of some ITS goals, the other is that the specific findings in this study are not generally applicable in other areas. In a multiobjective programming approach for selecting non-independent transportation investment alternatives, a distance heuristic algorithm is developed (Teng et al., 1996). Four types of investment alternatives are proposed by the authors (Teng et al., 1996, pp.294-295): two alternatives are "independent" if they are not related; two alternatives are "complementary" if the results become better when two alternatives are implemented simultaneously; two alternatives are "substitutive" if these two alternatives can replace each other; three alternatives are "common complementary substitution" if one alternative can be complementary to the second alternative as well as substitutive to the third alternative. With the approach suggested by the author, a near-optimal solution can be obtained. However, there is a limitation in this study: a degree of independence is required for this approach. It is very difficult to measure with current knowledge. The authors did not suggest a method to measure the degree of independence in this study.

There are some other interesting studies in ITS benefits evaluation and planning. Unlike using National ITS Architecture and multiobjective decision analysis, the Case-Based Reasoning (CBR) method is a kind of empirical method for regional ITS planning (Khattak, 1996). In the CBR method, similar historic cases will be presented. Both experience and lessons learned from previous studies will be included in the database. Based on the experience from similar historic cases stored in the CBR database, the impact of a proposed ITS project will be estimated. An example is a CBA planning tool for Intelligent Transportation Systems (Khattak et al., 1996). In this study, an expert system called PLANiTS is proposed by the authors. Five CBR functions are built in PLANiTS: the first function in PLANiTS matches current case specification to similar historic cases; the second function ranks the similarities of historic cases to the current case; the third function analyzes historic cases with statistical analysis tools; the fourth function compares the current case with similar historic cases; the fifth function assimilates the new information of the current case for future use. According to the authors, three limitations exist in this study. First, it is difficult to find similar cases when the level of matching stringency increases. Next, it is hard to judge similarities between the current case with historic cases. Another limitation is that possible errors exist because of the difference between the current case with historic cases.

In general, the deployments of Intelligent Transportation Systems have impacts on the traffic flow, travel mode choice, and traffic assignment, which in turn have impact on the air quality. The benefits of ITS applications have been observed in the field tests. However, during the stage of planning, the benefits of ITS projects are still very hard to estimate because of inadequate data information. Fortunately, some analysis tools, for example, the IDAS software, have been developed to assist the evaluation and planning of ITS alternatives. With these tools, traffic engineers can compare the impact and cost-effectiveness of different alternatives. Some further research can be performed by using multi-objective or multi-criteria decision analysis techniques.

2.4 SUMMARY

It has been proved that the Geographic Information System (GIS) has fantastic capabilities of handling large scale of database, performing the spatial analysis, and visualizing the analysis results. Since a transportation system can be modeled on district, zone, link and point basis, GIS can be a great tool to perform the impact analysis in transportation planning and air quality analysis. To estimate the mobile source emissions, the vehicle fleet fraction, traffic volume, and emission factors are the most important parameters. All these parameters can be obtained from different sources. By integrating the mobile source emission models into the GIS environment, the calculation will become more convenient and reliable. Furthermore, the analysis results can be directly shown in maps or layouts, which is a big help for decision makes to understand the analysis. Based on the GIS framework for air quality analysis, it is possible to test the impact of Intelligent Transportation Systems. To examine the impact of ITS strategies, some other tools are necessary to assist the analysis. Then, the recommendation for developing ITS solutions to manage the air quality can be made based on the evaluation results.

CHAPTER 3. MODELING MOBILE-SOURCE EMISSIONS WITHIN GIS ENVIRONMENT

3.1 INTRODUCTION

Mobile source emissions are intrinsically spatial (Bachman et al., 2000). When vehicles are moving along their paths, the emission rates vary in spatial terms due to the changes in vehicles power output, speed, and some other factors such as the efficiency of engines. Therefore, to apply GIS in mobile source emissions modeling, the vehicle emission rates at different locations in the transportation system need to be explored.

To estimate the emissions, there are three general input arguments: vehicle fleet characteristics, traffic characteristics, and emission rate factors. In this study, to get the vehicle fleet characteristics such as vehicle type, model, year, engine type, etc., the vehicle registration data are aggregated. The data are obtained with the assistance of Texas Department of Transportation (TxDOT). After the data are aggregated, the vehicles are divided into five categories according to the Environmental Protection Agency (EPA) standards. The traffic characteristics, including the spatial characteristics of the transportation networks, are obtained from the urban transportation planning model. The data used in this study is from the Capital Area Metropolitan Planning Organization (CAMPO) of Austin, Texas. The emission factors are calculated by MOBILE6.0 emission factor model, which is published by EPA in 2002. Based on these inputs, the estimation of mobile source emissions is performed in a Geographic Information System (GIS) environment, which is ArcGIS 8.0.

3.2 TRAFFIC CHARACTERISTICS OF STUDY

In order to analyze the impacts of traffic on air quality, the data from the travel demand model acquired from the Capital Area Metropolitan Organization (CAMPO) is used in this study. The year of analysis is 2007 and the base year for the data is 1997.

The study area is composed of the following three counties:

- Hays County, which is in the south;
- Travis County, which is in the middle; and
- Williamson County, which is in the north.

The transportation network of the research area contains more than 7,000 nodes and about 13,000 links. The entire metropolitan area is divided into 1,117 zones. Figure 3.1 gives an overview of the transportation network in Austin metropolitan Area.

Figure 3.1 Austin Transportation Network

The roads in this network are classified into 11 types. A list of these 11 types of facilities is provided as following:

- IH35
- Other Freeway
- Expressway
- Principal Arterial Divided
- Principal Arterial Undivided
- Minor Arterial Divided
- Minor Arterial Undivided
- Collector
- Local Road

- Express Lane
- Ramp

The CAMPO transportation planning model is developed within the environment of TransCAD 4.0, which is a very populous transportation planning software package based on GIS technology. Therefore, digital maps can be directly exported from the transportation planning model, with all traffic characteristics carried on such as node coordination, link length, traffic volume, average vehicle speed, road type, travel time, capacity, etc. Figure 3.2 provides an overview of the ratio of volume and capacity on each link in the study area (Source: Capital Area Metropolitan Planning Organization Transportation Planning Model).

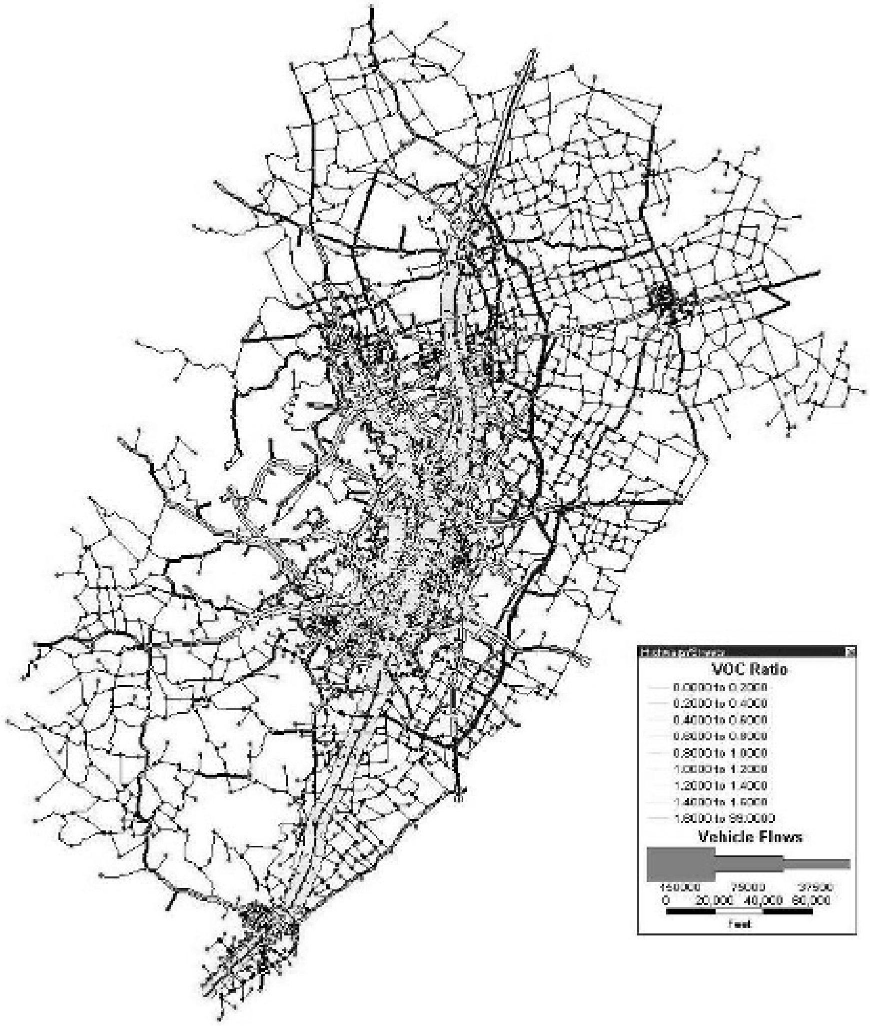


Figure 3.2 An Overview of the V/C Ratio for Austin Transportation Network

3.3 VEHICLE FLEET COMPOSITION

The analysis of the vehicle fleet composition is performed based on the vehicle registration data of Travis County (863,026 registered vehicles) and Williamson County (234,674 registered vehicles). An sample of the vehicle registration data was provided in table 3.1.

Table 3.1 Sample of the Vehicle Registration Data

VIN	YEAR	MAKE	MODEL	ENGINE TYPE	ADDRESS		ZIP
2T1FF28P61C529126	2001	TOYT	CEE	0	AUSTIN	TX	78759
1G1JC5119K7142575	1989	CHEV	CAV	0	AUSTIN	TX	78759
JHMCG5646XC039392	1999	HOND	ALX	0	AUSTIN	TX	78759
1G4HP54K624161564	2002	BUIC	LCF	0	AUSTIN	TX	78759
3G4AG55N0PS623389	1993	BUIC	CSP	0	AUSTIN	TX	78759
1G1JC5244V7121954	1997	CHEV	CAV	0	AUSTIN	TX	78759
19UYA42681A013570	2001	ACUR	32S	0	AUSTIN	TX	78759
1FMDU34X1PUC15061	1993	FORD	EPR	0	AUSTIN	TX	78759
WVWAH63B41P047943	2001	VOLK	PGS	0	AUSTIN	TX	78759
1HGCD5620RA009717	1994	HOND	UDX	0	AUSTIN	TX	78759
1FAFP40491F226851	2001	FORD	MUS	0	AUSTIN	TX	78759
1HGEJ6678TL057707	1996	HOND	UCL	0	AUSTIN	TX	78759
JH4DC2382SS000156	1995	ACUR	GSR	0	AUSTIN	TX	78759

Since the EPA MOBILE6.0 model is used to calculate the mobile emission factors, the vehicle classification standards suggested by EPA are employed in this study. According to the user's guide to MOBILE6.0 model (EPA, 2002), the vehicles in the United States can be categorized into 28 types. The classification standards are shown in table 3.2. Many of these individual classes are in pairs: a gasoline-fueled class, and a corresponding diesel-fueled class.

However, in this study, it is noticed that the vehicle registration data only represents all light duty vehicles that are licensed to operate on rods. The commercial vehicles, especially those heavy commercial trucks, are not included in the vehicle registration data. The information contained in the data set gives the vehicle identification number (VIN), year, make, model, and engine type (gasoline/diesel). According to the vehicle's make and model, all vehicles in the registration dataset are categorized into the following five groups:

- LDGV: Light-Duty Gasoline Vehicles (Passenger Cars);
- LDGT1: Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW);
- LDDV: Light-Duty Diesel Vehicles (Passenger Cars);
- LDDT12: Light-Duty Diesel Trucks 1and 2 (0-6,000 lbs. GVWR);
- LDDT34: Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR).

The categorization is completed manually within the Excel database. According to the vehicle year, make, engine type and model, all the vehicles are classified into the five categories above.

Most of the registered vehicles in Travis County and Williamson County are light duty gasoline vehicles and light duty gasoline trucks. The Light-Duty Gasoline Vehicles (LDGV) contain regular passenger cars such as sedans, couples, wagons, compact SUVs, and minivans. The Light-Duty Gasoline Trucks (LDGT) are composed of small trucks and full-size SUVs.

One problem encountered in this study is the classification of Sports Utility Vehicles (SUV). Since many drivers drive their SUVs to work, SUVs are basically treated as passenger cars. However, most of the SUVs are actually equipped with the same or similar engine and platform as light duty trucks. Considering the emission rates are basically determined by the engine, gross weight of the vehicle and vehicle speed, the SUVs are defined as light duty gasoline trucks (LDGT) in this study. There are some diesel passenger cars, which are categorized in to Light-Duty Diesel Vehicles (LDGV), but the number of this type of vehicles is very small.

Table 3.2 EPA MOBILE6.0 Vehicle Classifications

Number	Abbreviation	Description
1	LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
2	LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR*, 0-3,750 lbs. LVW**)
3	LDGT2	Light-Duty Gasoline Trucks 2 (0-6,000 lbs. GVWR, 3,751-5,750 lbs. LVW)
4	LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8,500 lbs. GVWR, 0-5,750 lbs. ALVW***)
5	LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8,500 lbs. GVWR, 5,751 lbs. and greater ALVW)
6	HDGV2b	Class 2b Heavy-Duty Gasoline Vehicles (8,501-10,000 lbs. GVWR)
7	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
8	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
9	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
10	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
11	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
12	HDGV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
13	HDGV8b	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
14	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)
15	LDDT12	Light-Duty Diesel Trucks 1and 2 (0-6,000 lbs. GVWR)
16	HDDV2b	Class 2b Heavy-Duty Diesel Vehicles (8,501-10,000 lbs. GVWR)
17	HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)
18	HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)
19	HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)
20	HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)
21	HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)
22	HDDV8a	Class 8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)
23	HDDV8b	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)
24	MC	Motorcycles (Gasoline)
25	HDGB	Gasoline Buses (School, Transit and Urban)
26	HDDBT	Diesel Transit and Urban Buses
27	HDDBS	Diesel School Buses
28	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)

(Source: User's Guide to MOBILE6.0, EPA, 2000.)
Note:
* GVWR—Gross Vehicle Weight Rating;
** LVW—Loaded Vehicle Weight;
*** ALVW—Adjusted Load Vehicle Weight.

The vehicle fleet composition in Austin area is shown in table 3.3.

Table 3.3 Fleet Composition of the Registered Vehicles in Austin Metropolitan Area

Vehicle Classification	Percentage
LDGV	66.04%
LDGT1	31.62%
LDDV	0.17%
LDDT12	1.78%
LDDT34	0.39%

A pie graph is created to show the composition of the vehicle fleet in Austin, TX (please see figure 3.3). From the graph, it can be seen that the light duty gasoline vehicles and light duty gasoline trucks account for more that 97% of the total registered vehicles in Travis County and Williamson County. All the registered vehicles are light duty vehicles.

All the vehicle registration data for Travis County and Williamson County are obtained. However, the data for Hays County, which is also part of the study area, are not obtained. So an assumption is made that the composition of the vehicles in Hays County is the same as the fleet composition in Travis County and Williamson County.

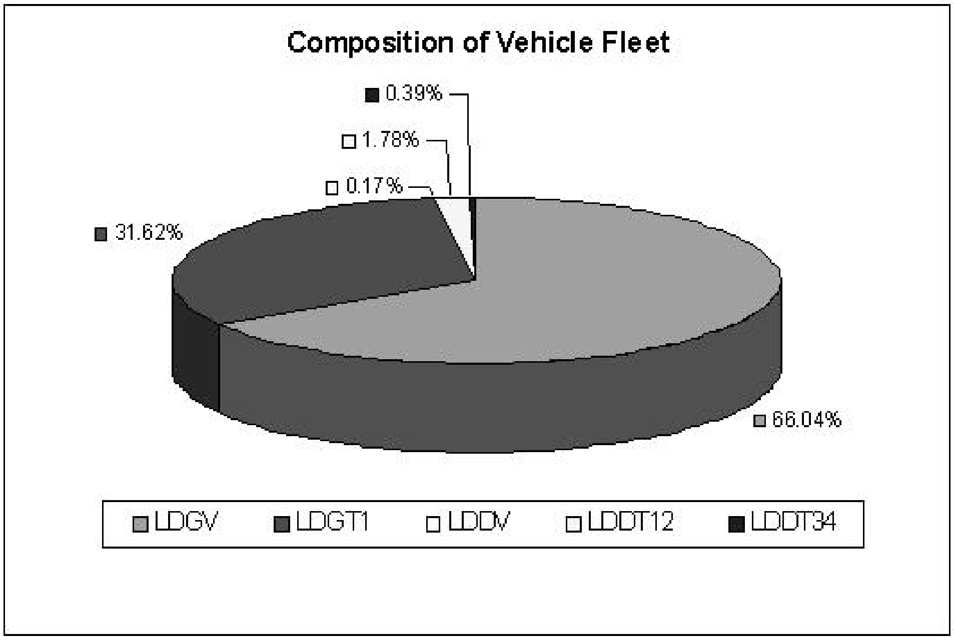


Figure 3.3 Fleet Composition of Registered Vehicles in Austin, TX

3.4 EMISSION FACTORS

The emission factors for HC, NOx and CO are developed with EPA MOBILE6.0 Model. MOBILE6.0 Model is a software package that can provide estimates of current and future emissions from all types of automobiles. According to the user's manual of MOBILE6.0 Model (EPA, 2002), it can be used to calculate average in-use fleet emission factors for:

- Three criteria pollutants: hydrocarbons (HC), carbon monoxide (CO), and oxide nitrogen (NOx).
- Gas, diesel and natural-gas-fueled cars, trucks, buses, and motorcycles.
- Calendar years between 1952 and 2050.

In the MOBILE6.0 model, there are 26 input parameters. These parameters are provided as below:

- Calendar year
- Month (January, July)
- Hourly Temperature
- Altitude (High, low)
- Weekend/weekday
- Fuel characteristics (Reid vapor pressure, sulfur, Reformulated gasoline)
- Humidity, solar load, and air-conditioning fractions
- Registration (age) distribution by vehicle class
- Annual mileage accumulation by vehicle class
- Diesel sales fractions by vehicle class and model year
- Average speed distribution by hour and roadway
- Distribution of vehicle miles traveled by roadway type
- Engine starts per day and distribution by hour
- Engine start soak time distribution by hour
- Trip end distribution by hour
- Average trip length distribution
- Hot soak duration
- Distribution of vehicle miles traveled by vehicle class
- Full, partial, and multiple diurnal distribution by hour

- Inspection and maintenance (I/M) program description
- Anti-tampering inspection program description
- Stage II refueling emissions inspection program description
- Air-conditioning usage rates
- Natural gas vehicle fractions
- HC species output
- Output format specifications and selections

Some of these 26 input parameters are difficult to obtain. However, most of these inputs are optional because the MOBILE 6.0 model supplies default values unless alternate data are provided. The minimum requirements for the input data include calendar year, minimum and maximum daily temperature, and fuel volatility. The default values represent "national average" values. Users who desire a more precise estimate of local emissions can substitute information that more specifically reflects local conditions. Use of local input data will be particularly common when the local emission inventory is to be built up from separate estimates of roadways, geographic areas, or times of day, in which fleet or traffic conditions vary considerably.

The descriptive output from MOBILE6.0 model provides emission rates in grams of pollutant (HC, CO or NOx) per vehicle mile traveled (g/mi). For a given vehicle category, the change in emission rates over time is due to fleet turnover, through which older vehicles built to less stringent emission standards are replaced by newer vehicles built to comply with more stringent standards. Therefore, emission rates from MOBILE can be combined with estimates of travel activity (total vehicle miles traveled, or VMT), which also change over time, to develop highway vehicle emission inventories expressed in terms of tons per hour, day, month, season, or year.

With adjustments to the basic emission rates, the emission rates of hydrocarbons (HC), carbon monoxide (CO); and oxides of nitrogen (NOx) are derived from MOBILE6.0 model respectively. Table 3.4 and table 3.5 provide an example of the emission rates output. For detailed information about emission rates, please see Appendix A.

Table 3.4 Example of Emission Rates Derived fro MOBILE6.0 Model

Pollutant	Speed	LDGV	LDGT1	LDDV	LDDT12	LDDT34	All Veh.
CO	2.5	96.755	109.477	4.566	4.983	35.198	97.189
CO	3	82.16	93.089	4.38	4.78	33.767	83.408
CO	4	63.916	72.484	4.037	4.406	31.12	65.933
CO	5	52.97	60.055	3.727	4.068	28.733	55.237
CO	6	45.672	51.748	3.448	3.762	26.577	47.967
CO	7	40.46	45.811	3.195	3.486	24.628	42.679
CO	8	36.55	41.36	2.966	3.237	22.863	38.646
CO	9	33.509	37.903	2.758	3.01	21.264	35.461
CO	10	31.077	35.142	2.57	2.805	19.812	32.876
CO	11	29.087	32.887	2.399	2.618	18.493	30.735
CO	12	27.428	31.01	2.243	2.448	17.294	28.931
CO	13	26.025	29.425	2.102	2.294	16.201	27.389
CO	14	24.822	28.068	1.972	2.153	15.205	26.056
CO	15	23.779	26.892	1.855	2.024	14.297	24.892
CO	16	22.867	25.864	1.747	1.906	13.467	23.867
CO	17	22.062	24.956	1.649	1.799	12.709	22.957
CO	18	21.347	24.148	1.559	1.701	12.015	22.146
CO	19	20.707	23.423	1.476	1.611	11.379	21.416
CO	20	19.851	22.579	1.401	1.529	10.797	20.538
CO	21	18.806	21.505	1.331	1.453	10.264	19.493
CO	22	17.856	20.526	1.268	1.384	9.774	18.543
CO	23	16.989	19.63	1.21	1.32	9.325	17.674
CO	24	16.194	18.807	1.156	1.262	8.912	16.878
CO	25	15.463	18.048	1.107	1.208	8.534	16.146
CO	26	14.787	17.346	1.062	1.159	8.186	15.47
CO	27	14.162	16.695	1.021	1.114	7.867	14.845
CO	28	13.582	16.089	0.983	1.072	7.574	14.266
CO	29	13.042	15.524	0.948	1.034	7.305	13.727
CO	30	12.537	14.996	0.916	0.999	7.059	13.226
CO	31	12.065	14.502	0.886	0.967	6.833	12.758
CO	32	11.623	14.039	0.86	0.938	6.627	12.321
CO	33	11.207	13.605	0.835	0.911	6.438	11.912
CO	34	10.816	13.196	0.813	0.887	6.267	11.529
CO	35	10.448	12.811	0.793	0.865	6.111	11.169
CO	36	10.099	12.449	0.774	0.845	5.969	10.831
CO	37	9.77	12.107	0.758	0.827	5.842	10.514
CO	38	9.458	11.784	0.743	0.811	5.728	10.215
CO	39	9.162	11.478	0.73	0.796	5.626	9.933
CO	40	8.88	11.189	0.718	0.784	5.536	9.668

Table 3.5 Example of Emission Rates Derived fro MOBILE6.0 Model (continued)

Pollutant	Speed	LDGV	LDGT1	LDDV	LDDT12	LDDT34	All Veh
CO	41	8.613	10.915	0.708	0.773	5.458	9.418
CO	42	8.358	10.656	0.699	0.763	5.39	9.181
CO	43	8.115	10.409	0.692	0.755	5.333	8.959
CO	44	7.883	10.175	0.686	0.748	5.286	8.748
CO	45	7.661	9.952	0.681	0.743	5.249	8.55
CO	46	7.449	9.74	0.677	0.739	5.222	8.363
CO	47	7.247	9.537	0.675	0.737	5.204	8.186
CO	48	7.052	9.342	0.674	0.736	5.196	8.019
CO	49	7.052	9.342	0.674	0.736	5.198	8.026
CO	50	7.052	9.342	0.676	0.737	5.208	8.035
CO	51	7.052	9.342	0.678	0.74	5.229	8.047
CO	52	7.052	9.342	0.682	0.744	5.259	8.062
CO	53	7.052	9.342	0.687	0.75	5.299	8.079
CO	54	7.052	9.342	0.694	0.757	5.349	8.1
CO	55	7.052	9.342	0.702	0.766	5.409	8.123
CO	56	7.842	10.494	0.711	0.776	5.48	8.954
CO	57	8.633	11.645	0.721	0.787	5.562	9.788
CO	58	9.423	12.797	0.734	0.801	5.655	10.626
CO	59	10.214	13.948	0.747	0.815	5.76	11.468
CO	60	11.004	15.1	0.763	0.832	5.878	12.313
CO	61	11.795	16.251	0.78	0.851	6.01	13.163
CO	62	12.585	17.402	0.798	0.871	6.155	14.018
CO	63	13.376	18.554	0.819	0.894	6.316	14.877
CO	64	14.166	19.705	0.842	0.919	6.493	15.742
CO	65	14.957	20.857	0.867	0.947	6.686	16.613

3.5 ESTIMATE MOBILE SOURCE EMISSIONS WITHIN GIS

According to the emission rates derived from the MOBIL6.0 model, it can be seen that emission rates of vehicles vary at different speed. Then, mobile source emissions of the vehicle fleet can be calculated based on traffic volume, vehicle mile traveled and emission rate factors. The formula, which is used to calculate the emissions on a certain road segment, is described as:

$$E_i = \sum_{j=1}^{N} \sum_{k=1}^{V} C_{ijk} \cdot D_{jk} \tag{3.1}$$

where

E_i — the emission of pollutant i (gram);

C_{jk} — the emission rate of vehicle j at speed k for pollutant i (gram/mile or gram/Km);

D_{jk} — the distance vehicle j traveled at speed k (km or mile);

N — number of vehicles traveled on that road segment;

V — the speed range of the moving traffic on that road segment.

Within the Geographic Information System (GIS) environment, the database can be manipulated to calculate the emissions in grams of each pollutant on each link. The total amount of mobile source emissions (HC, NOx and CO) generated by Austin transportation system is estimated based on the formula described above. The computation results are provided in figure 3.4. From the bar chart, it can be seen that the road traffic on Austin transportation network generate about 58 tons of NOx everyday, 48 tons of HC and 336.2 tons of CO. The total amount of CO is significantly higher than the other two pollutants. The reason is that the emission rates of CO are higher than the emissions of HC and NOx, especially when the vehicle speed is low. Please see the Appendix A for detailed information.

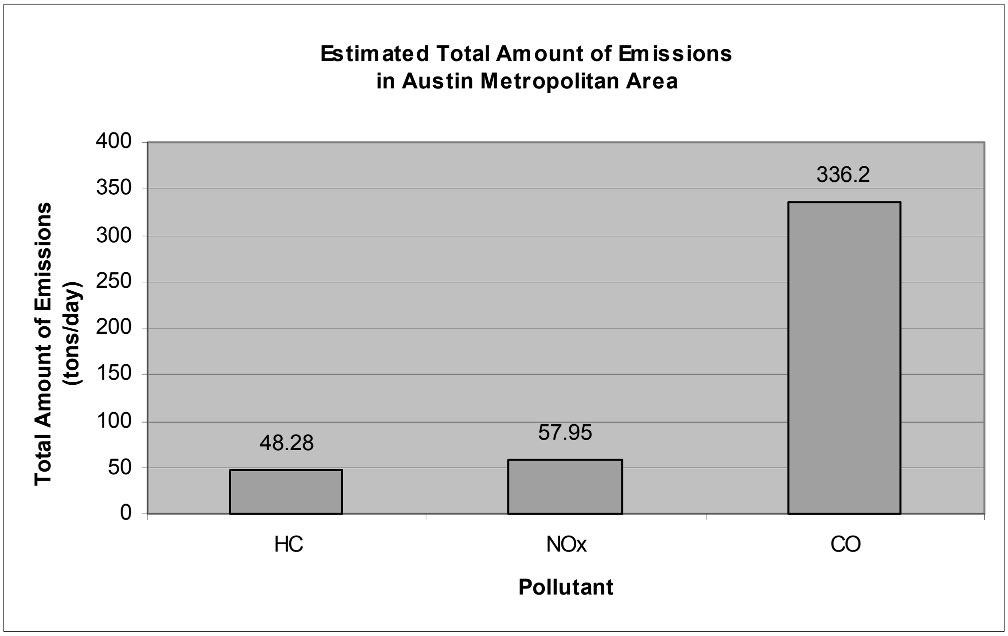


Figure 3.4 Estimated Total Amount of Emissions in Austin Metropolitan Area

Except for the total amount of each pollutant, the total amounts of emission on each facility type are also calculated. As described in section 3.2, the CAMPO transportation planning model categorizes the roads into 11 facility types. Within GIS database, the estimated emissions on each type of facilities are summed up. The results are shown in table 3.6.

Table 3.6 Total Amount of Emissions by Each Facility Type

	HC (tons/day)	NOx (tons/day)	CO (tons/day)
IH35	9.19	18.97	61.64
Other Freeway	6.12	6.99	39.87
Expressway	0.96	1.04	6.40
Principal Arterial Divided	14.48	14.19	102.54
Principal Arterial Undivided	4.90	5.02	34.03
Minor Arterial Divided	4.81	4.44	35.06
Minor Arterial Undivided	0.32	0.29	2.35
Collectors	0.03	0.03	0.26
Locals	0.05	0.06	0.36
Express Lanes	1.95	1.73	14.44
Ramps	5.46	5.18	39.24

The table above gives the estimated amount of emissions on each type of facilities. Because of the high traffic volume, the emissions generated from IH35, other freeway, expressway, ramps and principal arterials are higher than the emissions from minor roads, collectors and local roads.

In order to demonstrate the emission contributions of the traffic on each type of facilities, three pie graphs are developed to show the percentages of the emissions generated on each type of facilities. Figure 3.5 indicates the contribution of the traffic on each type of facility to hydrocarbon. Figure 3.6 shows the contribution of the traffic on each type of facility to oxide nitrogen. Figure 3.7 demonstrates the contribution of the traffic on each type of facility to hydrocarbon.

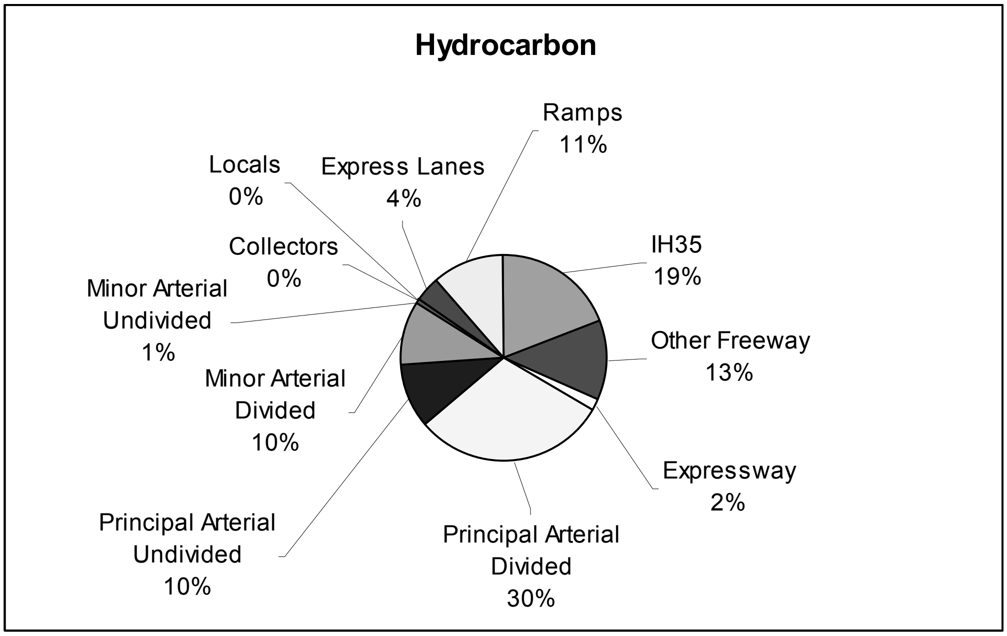


Figure 3.5 The Hydrocarbon Contribution of Each Type of Facility

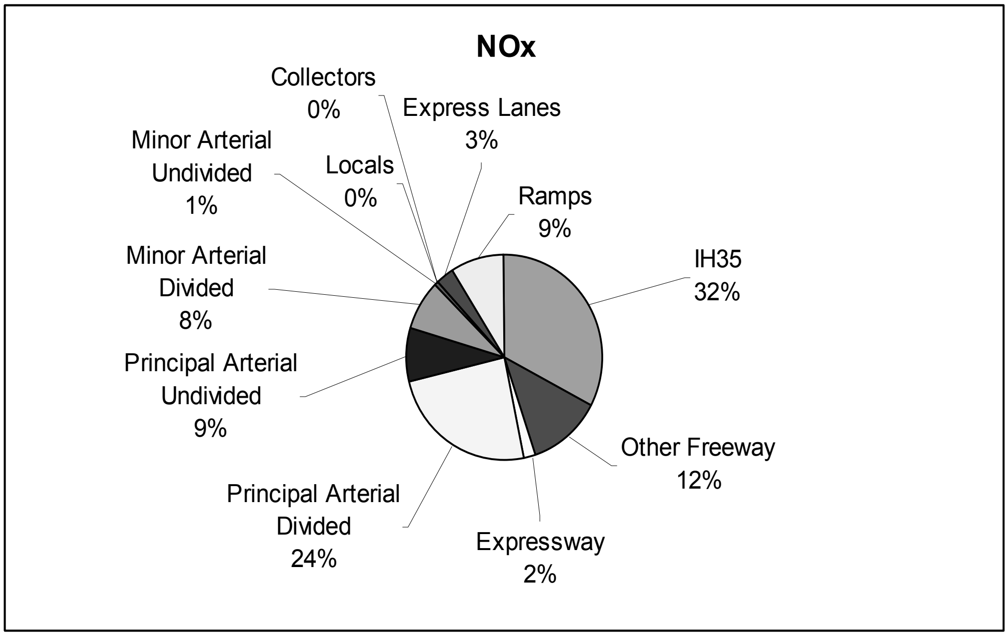


Figure 3.6 The Oxide Nitrogen Contribution of Each Type of Facility

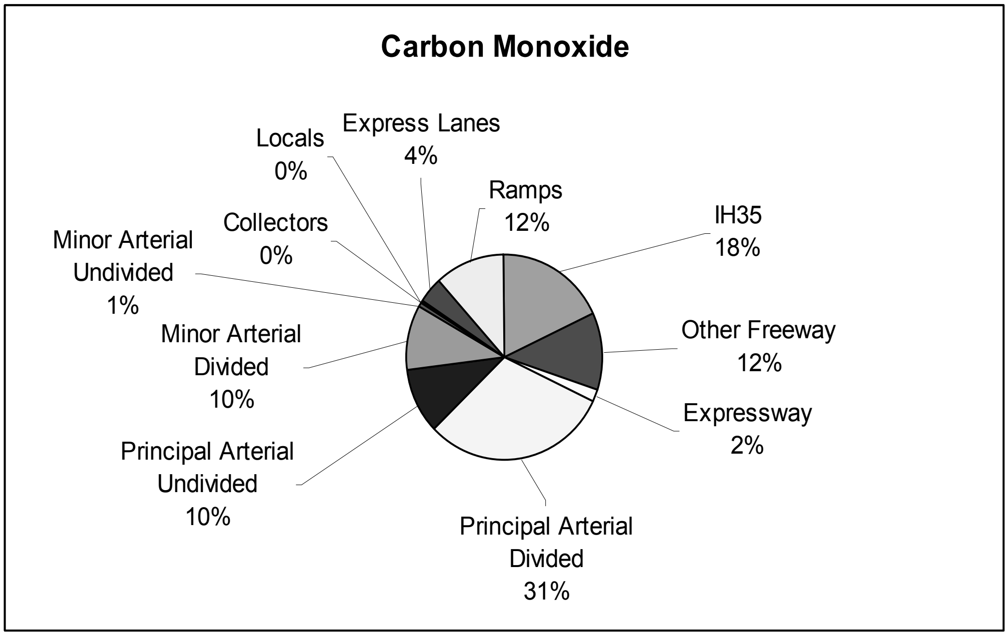


Figure 3.7 The Carbon Monoxide Contribution of Each Type of Facility

The results imply that the traffic on divided principal arterials are the largest source of HC (30%) and CO (31%) while the traffic on IH 35 are the largest source of NOx (32%). However, if we count the freeway and expressway together, it can be seen that 34% of HC, 46% of NOx and 32% of the CO are generated by the traffic on the freeway/expressway system in Austin metropolitan area. Meanwhile, the traffic on principal arterials also contribute a significant part to the total emissions. 40% of the HC, 33% of the NOx and 41% of the CO are generated by the traffic on principal arterials. Therefore, according to the estimation results, about 75% of the total emissions are generated on the freeways/expressways and principal arterials.

As we know, GIS has the special ability to visualize the spatial analysis results. The GIS model can automatically process the digital maps and show the results based on the user-defined cell size. The spatial concentration rates of the major mobile source pollutants, which are HC, NOx and CO, are mapped to the analysis area. The concentration rates along the road segments are calculated based on daily traffic, in terms of gram/mile.

The purpose of mapping the spatial concentration rates of these pollutants is to help readers or decision-makers to understand the air quality issues in the study area. On the other hand, with the help of these maps, the highway and street segments with high pollutant concentration rates can be identified more easily.

Figure 3.8 shows the concentrate rate of HC in Austin area.

Figure 3.9 shows the concentrate rate of NOx in Austin area.

Figure 3.10 shows the concentrate rate of CO in Austin area.

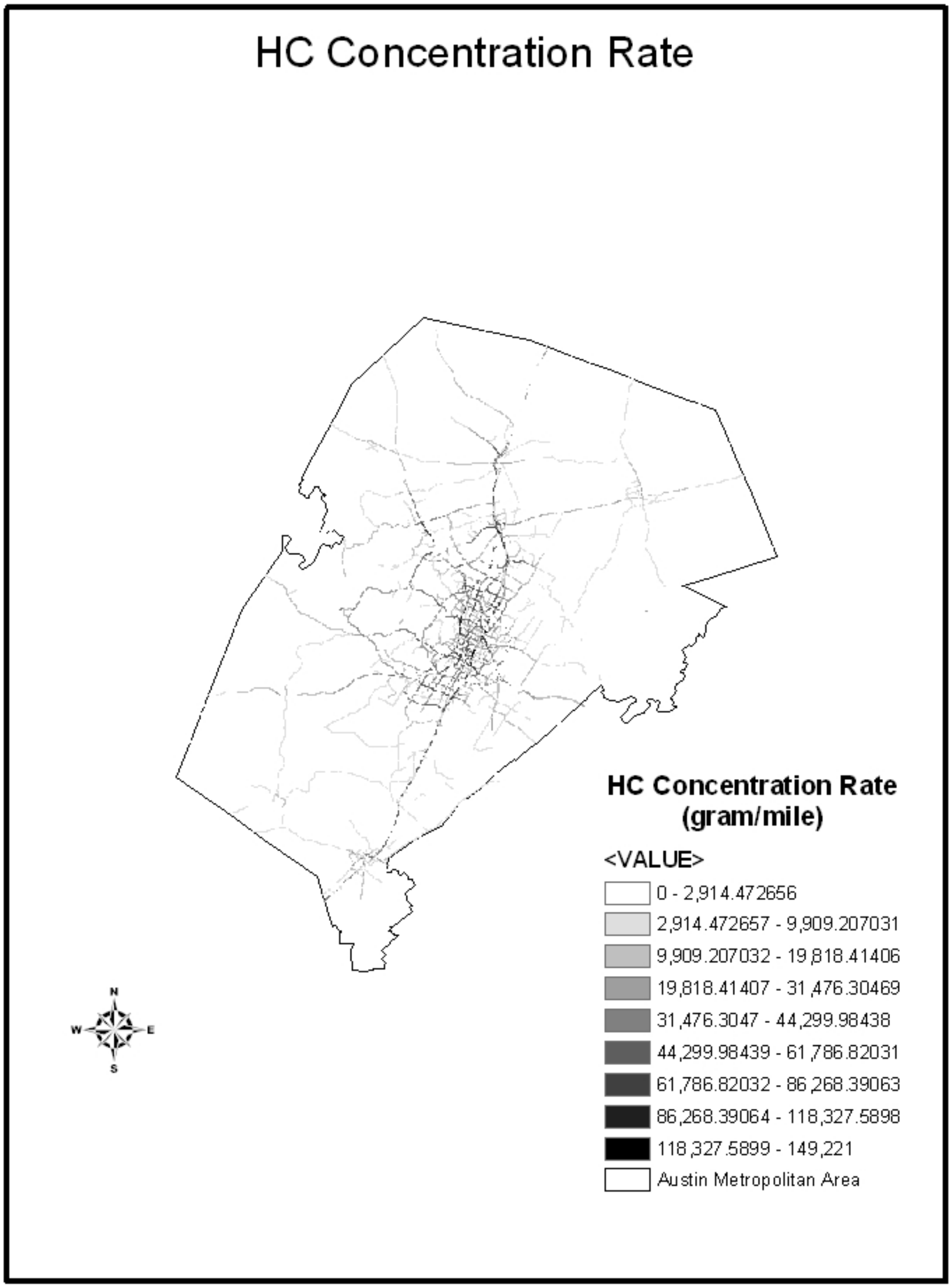


Figure 3.8 Concentrate Rates of HC in Austin Metropolitan Area

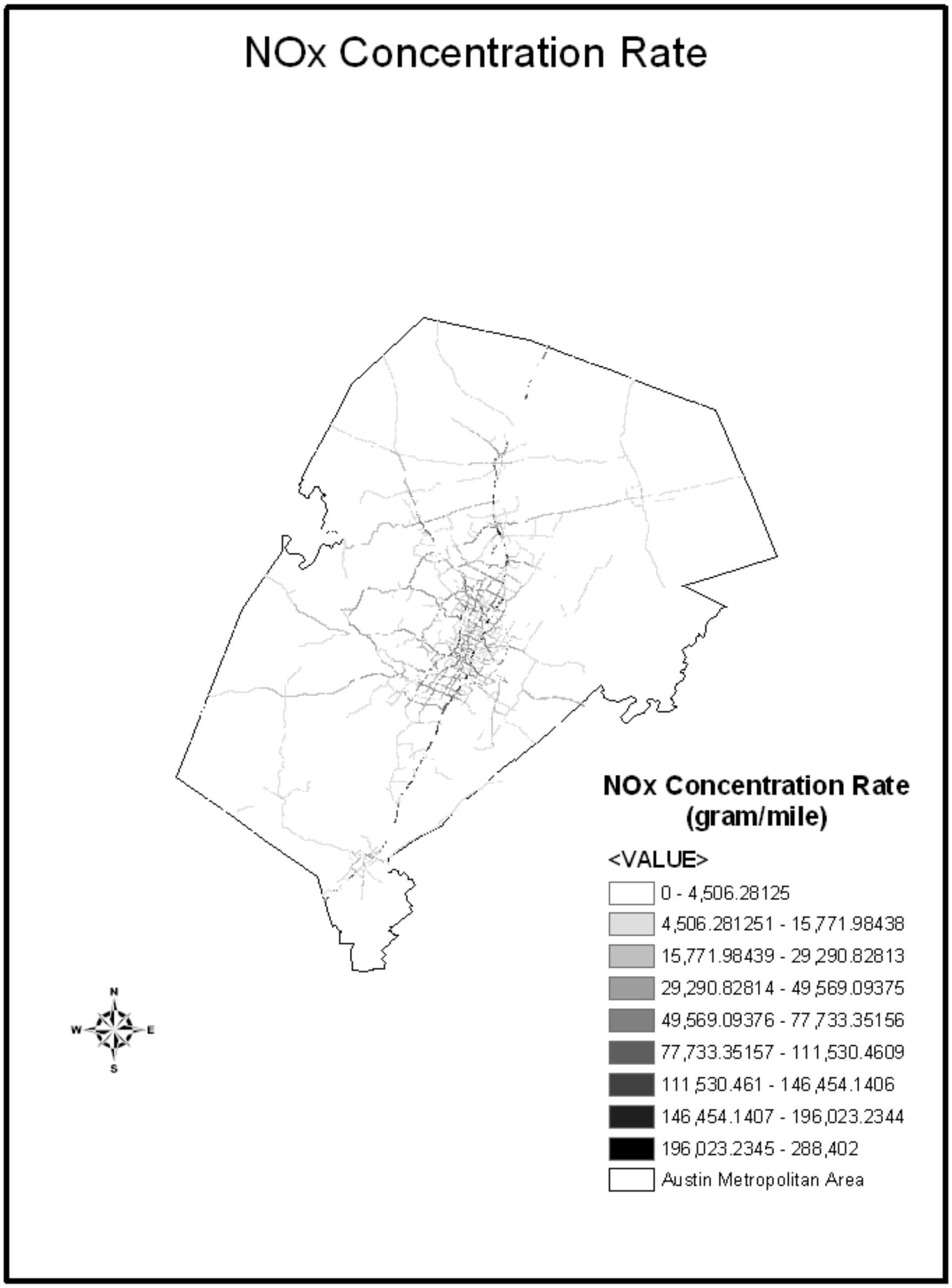


Figure 3.9 Concentrate Rates of NOx in Austin Metropolitan Area

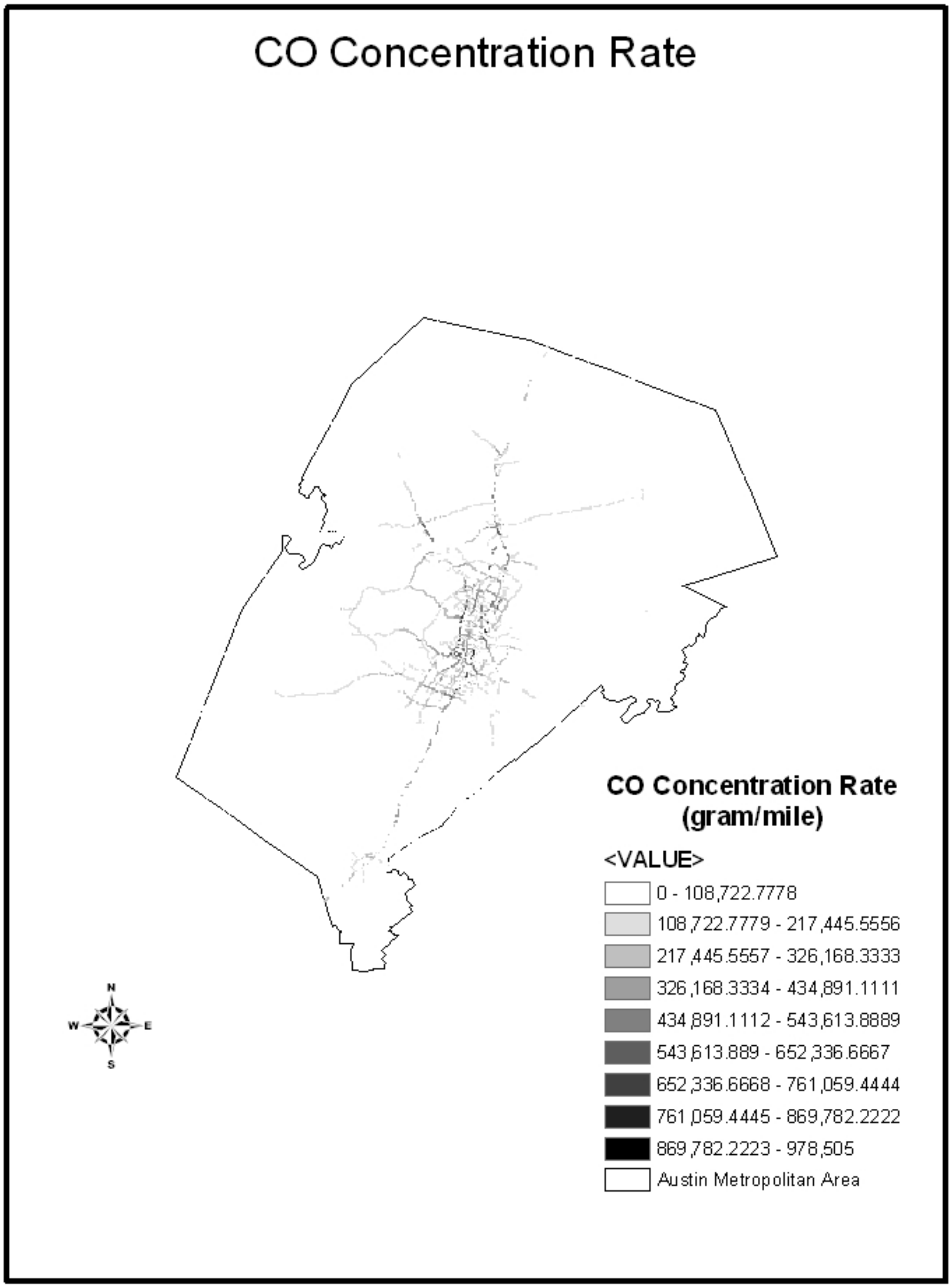


Figure 3.10 Concentrate Rates of CO in Austin Metropolitan Area

The pollutant concentration rate graphs provide the evaluation of the transport-related air pollution situations in Austin area. From the graphs, it can be seen that the freeway systems in Austin, which include IH-35, Loop 1, north 183, and US-71/Ben White, have very high concentration rate of the three major pollutants. The highest concentration rate of pollutants is on a road segment on I-35. According to the traffic data collected by TxDOT Austin district office, during the peak hours, the average speeds of the vehicles on IH-35 vary from 15 ~ 60 miles/hour on different links. In the downtown area, the average speed can be as low as 15~30 miles/hour.

With the vehicle speed dropping to a low speed, the emission rates of the vehicles increase dramatically, especially for those heavy-duty commercial vehicles such as eighteen-wheelers. Figure 3.11 gives an example of the relationship between CO emission rates and vehicle speed.

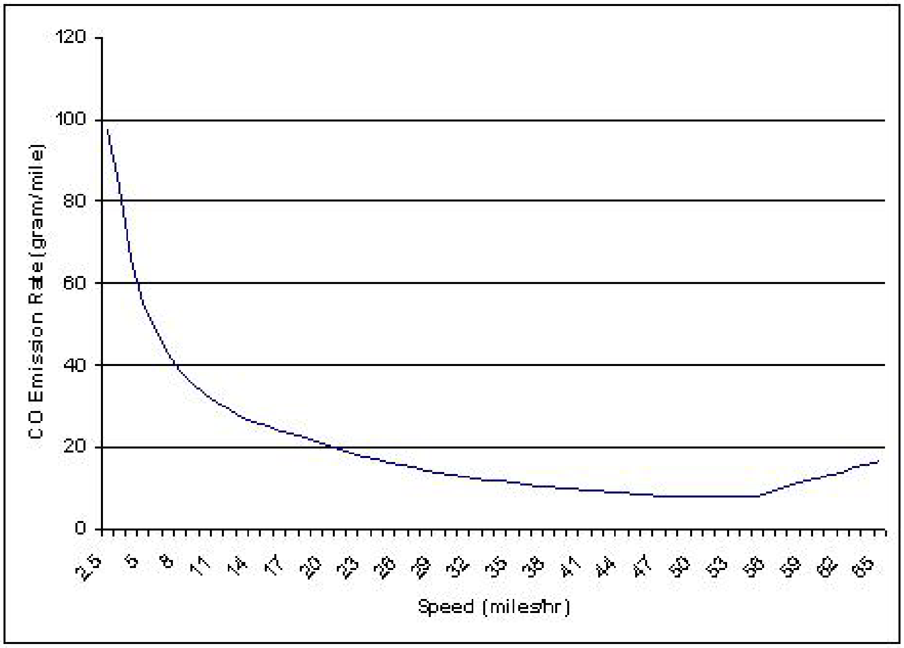


Figure 3.11 The Relationship between Emission Rate and Speed

One reason for the high pollutant concentration rate on IH 35 is because of the contribution of large volume of heavy-duty commercial trucks. Since the vehicle registration data obtained for this study do not contain the commercial trucks, some assumptions are made for calculation of the total emissions. An assumption is made on the heavy-duty truck traffic volume. According to the IH 35/SH 130 Through Truck Diversion Analysis (please see http://www.dot.state.tx.us/aus/mis/i35mis/trkstudy.htm, 1998), about 15% of the total daily traffic on south IH-35 and 10% of the total daily traffic on north IH-35 are trucks, based on 1996 data. Among the 15% of south IH-35 truck traffic, 60% of them are through traffic to downtown area. Among the 10% of north IH-35 truck traffic, 50% of them pass through the Austin downtown area. Therefore, in this study, it is assumed that 16% of the total daily traffic on south IH-35 and 11% of the total daily traffic on north IH-35 are heavy-duty trucks. The through truck traffic are 60% and 50% of the total truck traffic on south IH-35 and north IH-35 respectively. For Loop 1, US 183, US 71 and all other arterials and local roads, the concentration rates of emissions are calculated on the basis of obtained vehicle registration data.

CHAPTER 4. SELECT ITS STRATEGIES FOR EMISSIONS IMPROVEMENT

4.1 INTRODUCTION

4.1.1 Background

In most metropolitan areas in the United States, the transportation sector is a major source of air pollution. The transportation sector could have played a very important role in improving air quality by reducing the mobile-source emissions. However, it is a big challenge to improve the air quality without adversely reducing the mobility of the nation. As we know, the travel demand is expected to keep increasing in the next few years. On the other hand, it is unlikely that the capacity of the transportation infrastructure will be increased to meet the increasing demand due to the economic and political conditions. Therefore, it is very important to explore other options that may result in potential air quality benefits. ITS technologies are such class of to address the dilemma.

Since 1990s, Intelligent Transportation Systems (ITS) have been widely considered as a promising strategy to address current problems encountered in the transportation systems. The benefits of ITS include reducing delay, especially the non-recurring delay, improving traffic safety, enhancing the mobility of people and goods, promoting economic productivity and reducing the negative environmental impacts associated with traffic. As the federal and state governments push the deployments of ITS components and technologies, the evaluation and planning of ITS become more and more important due to the limited budget. Some professionals and decision makers have argued that the detrimental emission effects of increasing the number of vehicle trips and miles traveled may partially offset the potential environmental benefits of improved traffic operations and system efficiencies (EPA, 1998). In order to enhance the cost-effectiveness of the investments on ITS projects, especially the ITS strategies to reduce the negative impacts of highway traffic, a method is designed in this study for ITS strategies development and evaluation.

4.1.2 Description of the Methodology

In this study, ITS strategies for reducing mobile source emissions will be developed on the basis of the emission analysis in chapter 3.

As we know, the successful application of ITS is not only dependent on the quality of the technical components, but also on the ability of ITS to function effectively as an integrated system. Therefore, the system development and planning is very important for the successful deployment of ITS.

The National ITS Architecture is generally taken as the guideline for developing Intelligent Transportation Systems. It provides a common framework for planning, defining, and integrating intelligent transportation systems. It is a mature product that reflects the contributions of a broad cross-section of the ITS community. In 1993, the Federal Highway Administration (FHWA) released the ITS Planning Process Version 1.0, which is a system planning process provided as a guide to those undertaking regional ITS planning efforts. The latest version of FHWA ITS Planning Process, Version 2.1, has been released. Figure 4.1 gives an overview of the ITS Planning Process (Version 2.1) suggested by FHWA.

The FHWA ITS Planning Process is a very good reference for regional ITS planning. On the other hand, the field test results from previous studies on ITS benefits evaluation can be very useful supplements for ITS development and planning. Some analytical tools and programs are underway to assist the ITS development and planning. On the basis of FHWA ITS Planning Process, previous studies on ITS evaluation, National ITS Architecture and software programs available, a concise process is proposed in this study for ITS development and assessment. A flowchart was developed to show the process in figure 4.2.

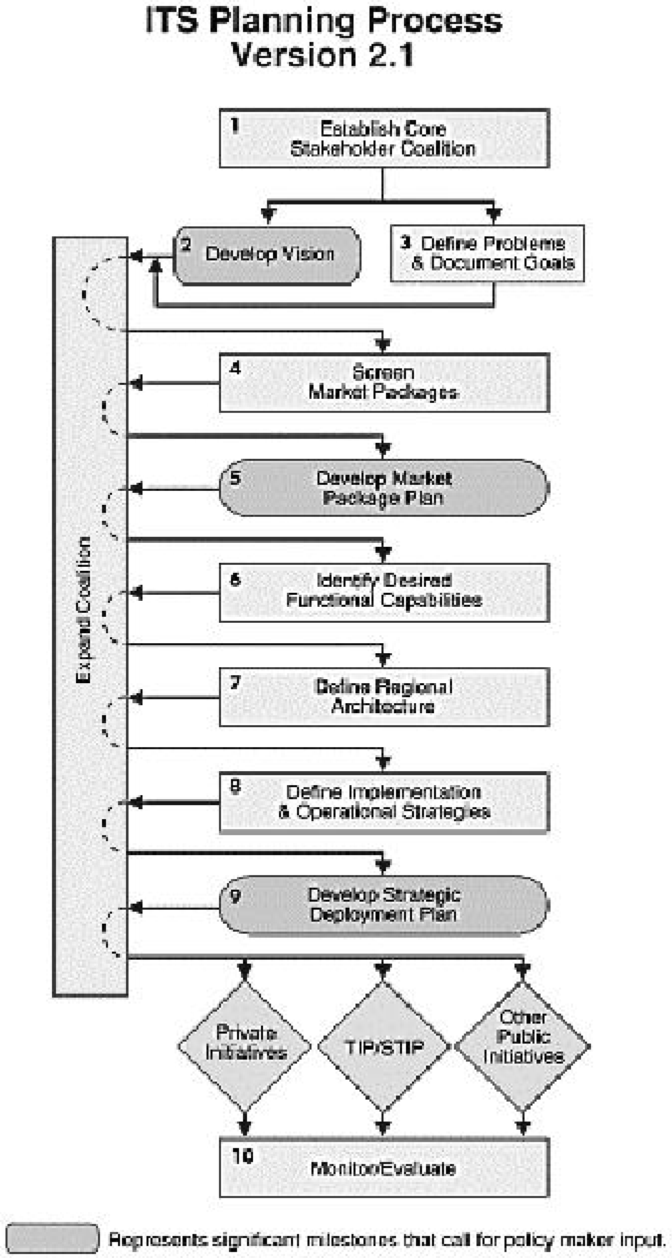


Figure 4.1 FHWA ITS Planning Process Version 2.1

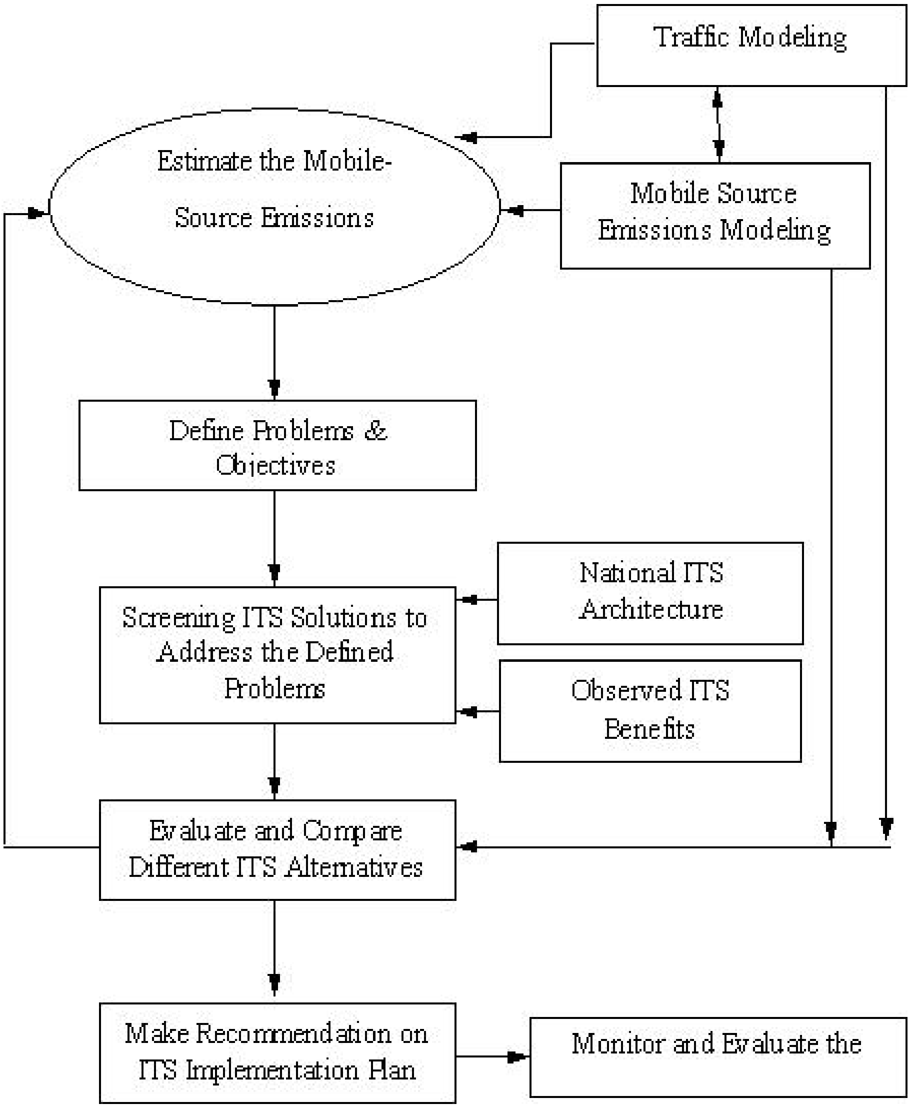


Figure 4.2 Select ITS Strategies for Emissions Improvement

As shown in the flowchart, the whole assessment process can be accordingly split into the four major steps:

- Step 1: Estimate the mobile-source emissions within GIS, which has already been described in chapter 3. Based on the estimation and analysis, the current emission problems and our objectives will be defined.
- Step 2: Screen ITS solutions/alternatives to address the defined problems. The national ITS architecture and previous studies, especially the field test results, will be taken as the main references.
- Step 3: Evaluate and compare different ITS alternatives. In this step, the software package for ITS benefits analysis will be used to examine those ITS alternatives screened in step 2.
- Step 4: Make recommendation on ITS implementation plan. Rational recommendations will be made for implementation according to the evaluation and comparison results from step 3.

4.2 DEVELOPMENT OF ITS STRATEGIES TO IMPROVE AIR QUALITY

4.2.1 Method for ITS Strategies Development

According to the experience from nation wide practice and professionals in this field, in committing to an investment of ITS program, the decision makers and executives need to define the best deployments and relevant policies for the ITS program. To develop the ITS strategies to improve air quality, the following three questions should be concerned on:

1. What are the major causes of the emissions in the study area?
2. What are the components of an ITS program to best address the emissions problem?
3. What practices should be defined for implementation to achieve the best operational benefits and cost-effectiveness?

Within the GIS framework, the current status of the emission level and causes of the emissions have already been estimated. As described in chapter 3, 34% of HC, 46% of NOx and 32% of the CO are generated by the traffic on the freeway/expressway system in Austin metropolitan area. Meanwhile, the traffic on principal arterials also contribute a significant part to the total emissions. 40% of the HC, 33% of the NOx and 41% of the CO are generated by the traffic on principal arterials. According to the estimation results, about 75% of the total emissions are generated on the freeways/expressways and principal arterials. Therefore, the ITS strategy design should focus on the freeway system and principal arterials in Austin area.

The freeway systems in Austin area include the following freeways: IH-35, US-290, US-183, and US-71. The principal arterials in Austin area include hundreds of miles of road segments such as Loop 360, RM 620, Lamar Blvd, RM 2222, Parmer Lane, Burnet Rd, 5th and 6th Street, etc.

Like many other states and cities, the Texas Department of Transportation (TxDOT) is the owner and responsible for the operations of the freeways and major corridor systems in Texas metropolitan areas. On the other hand, it is generally the city government's responsibility to maintain and operate the local principal arterials and streets. Thus, based on the national experience, the discussion about the traffic operations and ITS deployments generally refer to the state DOT owned properties such as freeways, state and US numbered highways in this study.

4.2.2 ITS Market Packages Screening

In the past decade, extensive effort has been done at the national level to provide guidance for ITS development. Many field tests have been completed to examine the effectiveness of ITS in addressing the transportation problems, including the environmental issues. The results of some field tests for ITS benefits evaluation are shown in table 4.1 (Source: Intelligent Transportation Systems Benefits: 2001 Updates). Since the mobile source emissions are highly related with delays, the benefits of ITS on delay are also shown in the table.

As described in the table, the National ITS Architecture defined nine interconnected subsystems. They are:

- Arterial Management Systems
- Freeway Management Systems
- Incident Management System
- Transit Management Systems
- Emergency Management Systems
- Electronic Toll Collection
- Electronic Fare Payment
- Highway-Rail Intersections
- Regional Multimodal Traveler Information

Each of the nine subsystems is made up of at least one equipment package. Equipment packages and market packages are two important concepts in the National ITS Architecture. An equipment package represents a set of equipment/capabilities which are likely to be purchased by an end-user to achieve a desired capability. Market packages provide another perspective that groups equipment packages that must be deployed together to provide a service. Market Packages represent particular groupings of entities defined in the Physical Architecture that correspond to specific transportation services. A market package is implemented with a combination of interrelated equipment. This equipment often resides in several different subsystems within the architecture framework and may be operated by different stakeholders. For example, the Automatic Vehicle Locating market package includes vehicle location equipment in the Transit Vehicle Subsystem and a base station element in the Transit Management Subsystem. In this example, all market package elements are owned and operated by the same transit stakeholder (Lockheed Martin Federal Systems, 1998).

Based on the ITS field tests and evaluation, it is found that ITS can provide significant benefits and support the particular transportation system objectives. The National ITS Architecture development joint team has also developed qualitative judgments of the benefits that can be expected from each of the market packages. Table 4.2 and table 4.3 (Source: ITS Performance and Benefit Study. Lockheed Martin Federal Systems, Odetics Intelligent Transportation Systems Division, June 1996) show the association between the market packages and the particular objectives of ITS.

Table 4.1 Observed Metropolitan ITS Benefits by Program Area

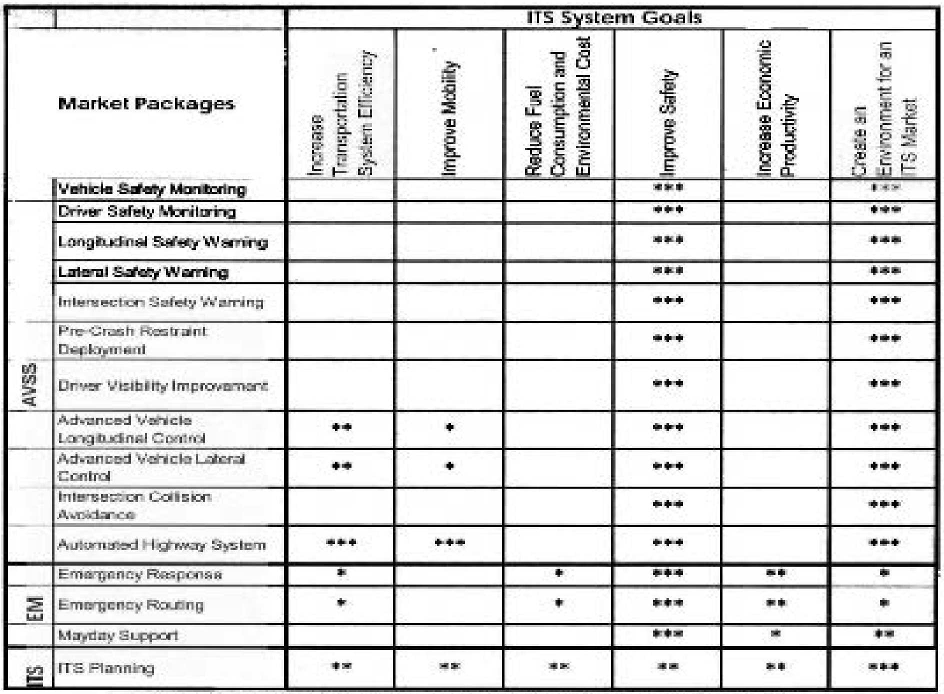
Metropolitan Benefits of ITS By Program Area		
Program Area	**Benefits Measure**	**Summary**
Arterial Management Systems	Delay Savings	Adaptive signal control has reduced delay from 14% to 44%
	Environmental	Improvements to traffic signal control have reduced fuel consumption 2% to 13%
Freeway Management Systems	Delay Savings	11 to 93.1 vehicle hours reduced due to ramp metering I-494: Minneapolis; Ramp Metering has shown 8% to 60% increases in speed on freeways
	Environmental	
Incident Management System	Delay Savings	Reductions range from 95 thousand to 2 million hours per year
	Environmental	TransGuide reduced fuel consumption up to 2600 gal/major incident
Transit Management Systems	Delay Savings	Reported improvements in on-time performance from 9% to 23% with CAD/AVL
	Environmental	
Emergency Management Systems	Delay Savings	
	Environmental	
Electronic Toll Collection	Delay Savings	Carquinez Bridge, CA: person time savings of 79,919 hours (per year) or about $1.07 million
	Environmental	Florida: Reduced CO 7.3%, HC 7.2%, Increased NOx 34% with 40% ETC usage
Electronic Fare Payment	Delay Savings	
	Environmental	
Highway-Rail Intersections	Delay Savings	
	Environmental	Automated horn warning system reduced noise impact area by 97%
Regional Multimodal Traveler Information	Delay Savings	San Antonio modeling results indicate a 5.4% reduction in delay for web site users
	Environmental	SmartTraveler Boston: estimated reductions NOx 1.5%, CO 33%

Table 4.2 Benefits of Market Packages for Achieving ITS System Goals

		ITS System Goals					
	Market Packages	Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity	Create an Environment for an ITS Market
APTS	Transit Vehicle Tracking	*	**	*		*	*
	Fixed-Route Operations	*	**	*		*	*
	Demand-Responsive Operations	*	**	*		*	*
	Passenger and Fare Management					**	*
	Transit Security				**		*
	Transit Maintenance					*	*
	Multi-modal Coordination	*	*			*	
ATIS	Broadcast Traveler Info	*	**	*			***
	Interactive Traveler Info	**	***	*			***
	Autonomous Route Guidance	**	***				***
	Dynamic Route Guidance	**	***	*	*		***
	ISP-Based Route Guidance	**	***	*	*		***
	Integrated Transportation Mgmt / Route Guidance	***	***	**	*		**
	Yellow Pages and Reservation		*				**
	Dynamic Ridesharing	**	*	*			*
	In Vehicle Signing		*		*		***
ATMS	Network Surveillance	*	*	*			*
	Probe Surveillance	*	*	*			**
	Surface Street Control	**	***	**	**		*
	Freeway Control	**	***	**	*		*
	Regional Traffic Control	***	***	***	**		*
	HOV and Reversible Lane Management	*	**	*			*
	Incident Management System	**	**	***	**		*
	Traffic Information Dissemination	**	*	*			*
	Traffic Network Performance Evaluation	**	**				*
	Dynamic Toll / Parking Fee Management					**	*
	Emissions and Environ. Hazards Sensing			***			**
	Virtual TMC and Smart Probe Data	*	*	*		*	*
CVO	Fleet Administration		***			***	**
	Freight Administration		***			***	**
	Electronic Clearance	**	***			***	**
	CV Administrative Processes					**	*
	International Border Electronic Clearance	**	***			***	**
	Weigh-In-Motion	**	***			***	**
	CVO Fleet Maintenance	*			**	**	*
	HAZMAT Management	*			**	**	*
	Roadside CVO Safety	*	**		**	**	**
	On-board CVO Safety				***	**	**

Key: * = low benefit, ** = moderate benefit, *** = high benefit

Table 4.3 Benefits of Market Packages for Achieving ITS System Goals (Continued)



		ITS System Goals					
	Market Packages	Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity	Create an Environment for an ITS Market
AVSS	Vehicle Safety Monitoring				***		***
	Driver Safety Monitoring				***		***
	Longitudinal Safety Warning				***		***
	Lateral Safety Warning				***		***
	Intersection Safety Warning				***		***
	Pre-Crash Restraint Deployment				***		***
	Driver Visibility Improvement				***		***
	Advanced Vehicle Longitudinal Control	**	*		***		***
	Advanced Vehicle Lateral Control	**	*		***		***
	Intersection Collision Avoidance				***		***
	Automated Highway System	***	***		***		***
EM	Emergency Response	*		*	***	**	*
	Emergency Routing	*		*	***	**	*
	Mayday Support				***	*	**
ITS	ITS Planning	**	**	**	**	**	***

Key: * = low benefit, ** = moderate benefit, *** = high benefit

The projected benefits can be aligned with specific needs of a deploying agency to select the proper market packages for implementation. As shown in the table, different objectives are supported by different groups of market packages. On the other hand, some market packages are capable of assisting multiple objectives. So evident is that these market packages should get the priority to be deployed. From the table, it can be seen that the following market packages support the objective of reducing fuel consumption and environmental costs (*—low benefits, **—moderate benefits, ***—high benefits):

APTS:

Transit Vehicle Tracking (*),

Fixed-Route Operations (*),

Demand Responsive Operations (*);

ATIS:

Broadcast Traveler Info (*),

Interactive traveler info (*),

Dynamic Route Guidance (*),

Integrated Transportation Management/Route Guidance (**),
Dynamic Ridesharing (*);

ATMS:
- Network Surveillance (*),
- Probe Surveillance (*),
- Surface Street Control (**),
- Freeway Control (**),
- Regional Traffic Control (***),
- HOV and Reversible Lane Management (*),
- Incident Management System (***),
- Traffic Information Dissemination (*),
- Emssions and Environmental Hazard Sensing (***),
- Virtual TMC and Smart Data (*);

EM:
- Emergency Response (*),
- Emergency Routing (*);

ITS:
- ITS Planning (**).

By mapping the functions/benefits of ITS market packages and the objective, which is to reduce the emissions generated by transportation sector, the ITS strategies to achieve the objective are recommended. These strategies include the following market packages:

- ATMS08—Incident Management System (***),
- ATMS07—Regional Traffic Control (***),
- ATMS11—Emissions and Environmental Hazard Sensing (***),
- ATMS04—Freeway Control (**),
- ATIS6—Integrated Transportation Management/Route Guidance (**), and
- ATIS1—Broadcast Traveler Info (*)

The labels of these market packages represent the inventory numbers defined in the National ITS Architecture. After screening the market packages, an important next step is to evaluate the potential benefits of the recommended market packages to address the environmental problem.

4.3 EVALUATE AND COMPARE DIFFERENT ITS ALTERNATIVES

4.3.1 Introduction of ITS Deployment Analysis System (IDAS)

Since the ITS market packages have already been screened, the next task is to estimate and quantify the potential benefits of these market packages. Generally, evaluation of air quality is a very complex process, as we have described in chapter 3. Evaluation of environmental benefits of ITS are further complicated by the facts that deployments of most ITS strategies have been relatively recent, and are largely still underway. Therefore, the long-term relationships between these ITS strategies and the factors that affect air quality are really difficult to estimate. However, after reviewing the previous studies, we noticed that there are still some methods and tools can be employed for ITS evaluation. One of such tools is Intelligent Transportation System Deployment Analysis System (IDAS).

IDAS is a sketch-planning tool designed to assist transportation planners and ITS specialists with completing a comparative cost-benefit analysis for potential ITS projects. It can be used to estimate impacts, benefits, and costs attributed to deploying ITS components. IDAS is a post-planning tool that requires travel demand models to be processed before being imported. IDAS is also capable of implementing mode split and traffic assignment steps associated with the traditional model. IDAS is used to analyze alternatives, not to determine which ITS operations are optimal to use. For daily time period analysis, the induced/forgone demand option is available. IDAS is able to estimate various impacts including (Cambridge Systematics 2001):

- Changes in user mobility
- Travel time/speed
- Travel time reliability
- Fuel costs
- Operating costs
- Accident costs
- Emissions

- Noise

In IDAS Model, performance is given by market sector, facility type, and district. These modules, which correspond to different performance measures, are available for analyses (Cambridge Systematics 2001):

- Input/Output Interface Module (IOM);
- Alternatives Generator Module (AGM);
- Benefits Module;
- Cost Module;
- Alternatives Comparison Module.

Compare to other ITS evaluation program such as SCRITS, IDAS is a complicate program to evaluate ITS options. Basically, IDAS can estimate the costs as well as the benefits of an ITS option. The outputs of IDAS is the costs and benefits of the ITS options in dollars. A benefit-cost ratio is calculated for each ITS option. All of the ITS options benefits are measured in dollars. For example, IDAS use the average value of time to measure the benefits of time savings, travel time reliabilities, etc. In order to apply IDAS to a certain area, some parameters in the program need to be customized. For instance, the average fuel price, the average value of time, etc. If the parameters are difficult to measure, then the default values in IDAS programs can be used. An example is the emission costs ($/ton). IDAS program gives the basic values for the costs of hydrocarbons, carbon monoxides, nitrous oxides, etc. If users have no way to customize these values, the default values can be applied.

The data required by IDAS model are exported from the transportation planning model developed by CAMPO. The dataset imported to IDAS are the same as the data imported to GIS framework for emissions estimation. The GIS and IDAS models have great compatibility of data sharing.

4.3.2 Experiment Design for ITS Market Packages Evaluation

As described in the section 4.2, six market packages have been proposed. IDAS program is capable of evaluating most of the six market packages except the package of Emissions and Environmental Hazard Sensing. In IDAS, under each market packages, ITS options must be developed to represent the deployments. Therefore, the following ITS options are selected to represent the corresponding market packages:

- Incident Detection and Response Systems — Incident Management System (ATMS08),
- Central Controlled Corridor Traffic Signal Coordination System — Regional Traffic Control (ATMS07),
- Central Controlled Ramp Metering Systems — Freeway Control (ATMS04),
- Freeway Dynamic Message Signs — Integrated Transportation Management/Route Guidance (ATIS6),
- Highway Advisory Radio — Broadcast Traveler Info (ATIS1).

The Emissions and Environmental Hazard Sensing (ATMS11) market package is very important and useful for urban air quality control. However, IDAS program does not develop a module to evaluate this market package. Therefore, this market package is recommended for implementation, but the potential benefits of this package is not discussed in this study.

The ITS options, including Incident Detection and Response Systems, Central Controlled Corridor Traffic Signal Coordination System, Central Controlled Ramp metering System, Freeway Dynamic Message Signs and Highway Advisory Radio, are tested with IDAS program. Freeways and some arterials in Austin area are selected for doing experiments. They are:

Freeways & Expressways:

- Interstate Highway 35. The testing segment starts at Braker Lane from the North and ends at Slaughter Lane to the South;
- US183. The testing segment starts at US290 from the south and ends at RM620 to the north;
- US71. ITS options are deployed on the freeway segment from IH35 on the east to William Cannon Rd on the west;
- LOOP1 (Mopac). The freeway segments between Parmer Lane and US71/US290 are selected for tests.

Arterials:

- Lamar Blvd. The road segments between US183 and US71/US290 Blvd are selected for experiments;
- Guadalupe Blvd. The road segments between North Lamar and the 1st Street are chosen for doing experiments;

- 38th Street. The segments of 38th street between LOOP1/Mopac and Guadalupe are selected for doing experiments;
- 5th Street and 6th Street in the downtown area.

In IDAS program, the ITS options representing the recommended ITS market packages are added on to these freeways and arterials. Then, the IDAS program will redo the traffic assignment and calculate the costs and potential benefits of the ITS options. The experiments completed in this study include:

- Deploying Incident Detection and Response Systems on the selected segments of Interstate Highway 35;
- Deploying Incident Detection and Response Systems on the selected segments of US 183;
- Deploying Incident Detection and Response Systems on the selected segments of LOOP1/Mopac;
- Deploying Incident Detection and Response Systems on the selected segments of US 71;
- Deploying Freeway Dynamic Message Signs on the selected segments of Interstate Highway 35;
- Deploying Freeway Dynamic Message Signs on the selected segments of US183;
- Deploying Freeway Dynamic Message Signs on the selected segments of LOOP1/Mopac;
- Deploying Freeway Dynamic Message Signs on the selected segments of US71;
- Deploying Central Controlled Ramp Metering Systems on the selected ramps of Interstate Highway 35;
- Deploying Central Controlled Ramp Metering Systems on the selected ramps of US183;
- Deploying Central Controlled Ramp Metering Systems on the selected ramps of LOOP1/Mopac;
- Deploying Central Controlled Corridor Traffic Signal Coordination Systems on selected arterials.

These experiments are designed to test the possible benefits and the cost-effectiveness of these ITS options/ITS packages in the transportation system of Austin. Obviously, the same ITS options or market packages can yield different impacts and benefits on different highways and arterials. Based on the experiment results, the recommended ITS market packages can be compared. Furthermore, the evaluation results can be used to assist the decisions on ITS deployments.

4.3.3 EVALUATION RESULTS ANALYSIS

The IDAS program has a graphic user interface (GUI). Therefore, it is easy for users to complete the operations in the program. Figure 4.3 shows two snap shots of IDAS interface.

The cost module of IDAS estimates the capital and operating cost of various ITS deployments within each ITS option. After the ITS option is deployed and the improvements are defined, the cost module will determine the equipment associated with the ITS deployments. The default equipment capital and operating costs will be applied unless the user defines these costs.

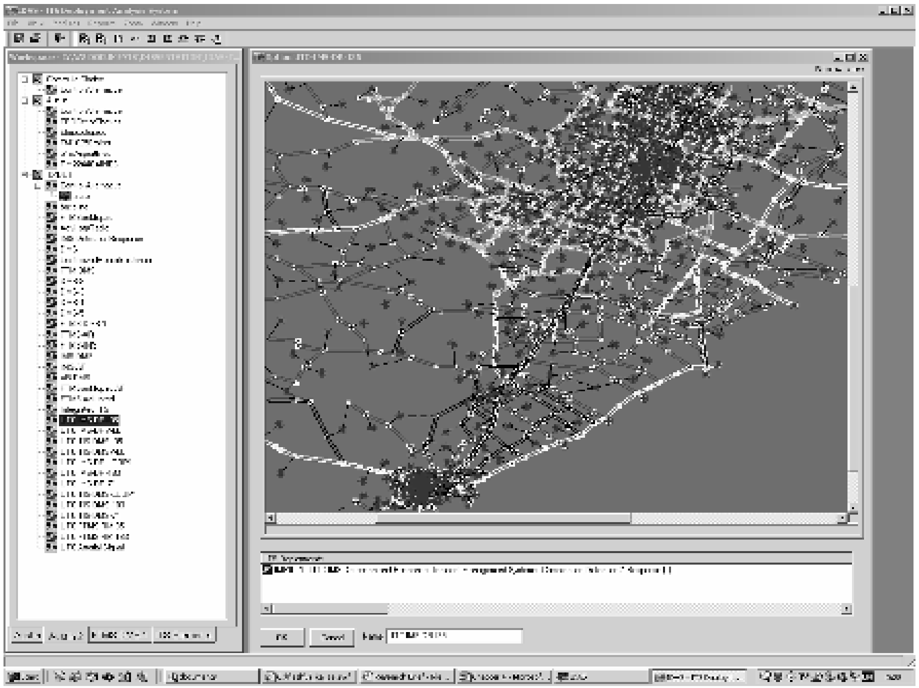


Figure 4.3 Edit ITS Options in IDAS

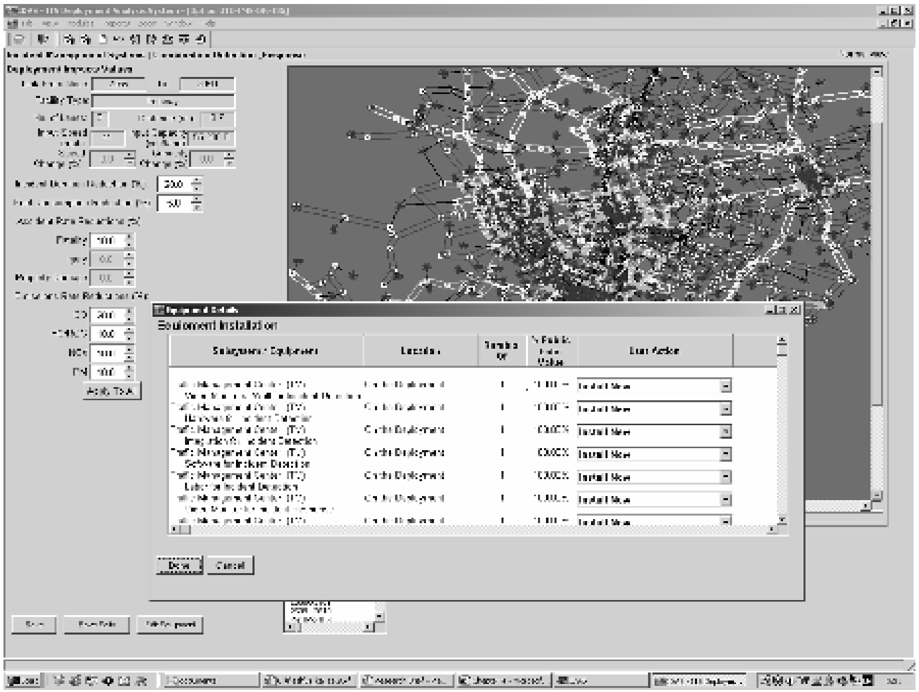


Figure 4.4 Edit Equipment of ITS Options in IDAS

There is a very important concept in IDAS, which is that the costs of equipment can be shared between different deployments. That is, if a particular piece of equipment is common between deployments within an ITS option, IDA can share the costs of the equipment and reflect this cost sharing savings in the resulting total annual average cost. So by sharing the equipment, a better benefit-cost ration may be obtained.

To calculate emissions impacts, IDAS program is capable of using three different models including MOBILE5a rates, California Air Resources Board (CARB) rates, and using user-specified rates. The IDAS program employed in this study is version 2.1, which was released in early 2002. However, MOBILE5a rates are still the default emission rates even though MOBILE6.0 model has been released since early 2002. To adjust the calculation, the emission rates derived from MOBLE6.0 model are defined to calculate the emissions impacts of ITS options in this study.

IDAS is capable of estimating emissions for hydrocarbons, carbon monoxide and nitrous oxides. The emissions module in IDAS applies emission rates based on the link travel speed and vehicle classification. Since the link travel speed and vehicle classification have already been developed in estimating the emissions within GIS framework (see chapter 3), the same speed data and vehicle classification data are used in IDAS model.

After running the analysis, the results are obtained for those defined tests. The benefits calculation results are shown in table 4.4 ~ table 4.7.

Table 4.4 Benefit-Cost Analysis of Incident Detection and Response Systems

Benefit/Cost Summary										
Benefits are reported in 2003 dollars										
Annual Benefits	**Weight**		**IMS on IH35**		**IMS on LOOP1**		**IMS on US183**		**IMS on US71**	
Change in User Mobility	1.00	$	0	$	0	$	0	$	0	$
Change In User Travel Time										
Travel Time Reliability	1.00	$	64	$	32	$	7	$	11	$
Change in Costs Paid by Users										
Fuel Costs	1.00	$	1,213,402	$	5,058,009	$	451,776	$	763,914	$
Non-fuel Operating Costs	1.00	$		$		$		$		$
Accident Costs (Internal Only)	1.00	$	568,390	$	1,448,755	$	210,788	$	348,565	$
Change in External Costs										
Accident Costs (External Only)	1.00	$	100,304	$	50,327	$	37,198	$	61,511	$
Emissions										
HC/ROG	1.00	$	102,819	$	51,027	$	37,708	$	60,937	$
Nox	1.00	$	267,621	$	134,356	$	98,622	$	164,586	$
CO	1.00	$	1,659,755	$	804,924	$	595,999	$	938,842	$
Noise	1.00	$	0	$	0	$	0	$	0	$
Total Annual Benefits		**$**	**3,912,355**	**$**	**1,946,877**	**$**	**1,432,102**	**$**	**2,338,372**	**$**
Annual Costs										
Average Annual Private Sector Cost		**$**	0	**$**	0	**$**	0	**$**	0	**$**
Average Annual Public Sector Cost		**$**	1,510,538	**$**	1,510,538	**$**	1,510,538	**$**	1,510,538	**$**
Total Annual Cost		**$**	**1,510,538**	**$**	**1,510,538**	**$**	**1,510,538**	**$**	**1,510,538**	**$**
Benefit/Cost Comparison										
Net Benefit (Annual Benefit - Annual Cost)		**$**	**2,401,817**	**$**	**436,339**	**$**	**-78,436**	**$**	**827,834**	**$**
B/C Ratio (Annual Benefit/Annual Cost)			**2.59**		**1.29**		**0.95**		**1.55**	

Table 4.5 Benefit-Cost Analysis of Freeway Dynamic Message Signs

Benefit/Cost Summary										
Benefits are reported in 2003 dollars										
Annual Benefits	**Weight**		**DMS on IH35**		**DMS on LOOP1**		**DMS on US183**		**DMS on US71**	
Change in User Mobility	1.00	$	31,528,354	$	12,690,698	$	9,698,951	$	14,007,000	$
Change In User Travel Time										
Travel Time Reliability	1.00	$		$		$		$		$
Change in Costs Paid by Users										
Fuel Costs	1.00	$		$		$		$		$
Non-fuel Operating Costs	1.00	$		$		$		$		$
Accident Costs (Internal Only)	1.00	$		$		$		$		$
Change in External Costs										
Accident Costs (External Only)	1.00	$		$		$		$		$
Emissions										
HC/ROG	1.00	$		$		$		$		$
Nox	1.00	$		$		$		$		$
CO	1.00	$		$		$		$		$
Noise	1.00	$		$		$		$		$
Total Annual Benefits		**$**	**31,528,354**	**$**	**12,690,698**	**$**	**9,698,951**	**$**	**14,007,000**	**$**
Annual Costs										
Average Annual Private Sector Cost		**$**	0	**$**	0	**$**	0	**$**	0	**$**
Average Annual Public Sector Cost		**$**	2,369,269	**$**	1,159,699	**$**	932,904	**$**	554,914	**$**
Total Annual Cost		**$**	**2,369,269**	**$**	**1,159,699**	**$**	**932,904**	**$**	**554,914**	**$**
Benefit/Cost Comparison										
Net Benefit (Annual Benefit - Annual Cost)		**$**	**29,159,085**	**$**	**11,531,000**	**$**	**8,766,046**	**$**	**13,452,087**	**$**
B/C Ratio (Annual Benefit/Annual Cost)			**13.31**		**10.94**		**10.40**		**25.24**	

Table 4.6 Benefit-Cost Analysis of Freeway Control Systems

Benefit/Cost Summary								
Project: Austin 2								
Benefits are reported in 2003 dollars			**Central Controlled Ramp Metering Systems on LOOP1**		**Central Controlled Ramp Metering Systems on I35**		**Central Controlled Ramp Metering Systems on US183**	
Annual Benefits	**Weight**							
Change in User Mobility	1.00	$	(3,111,337)	$	11,483,566	$	8,422,917	$
Change In User Travel Time								
Travel Time Reliability	1.00	$		$		$		$
Change in Costs Paid by Users								
Fuel Costs	1.00	$	1,197,994	$	333,806	$	251,949	$
Non-fuel Operating Costs	1.00	$	913,083	$	116,703	$	78,325	$
Accident Costs (Internal Only)	1.00	$	3,878,446	$	743,936	$	473,122	$
Change in External Costs								
Accident Costs (External Only)	1.00	$	684,423	$	131,282	$	83,491	$
Emissions								
HC/ROG	1.00	$	46,067	$	8,889	$	15,975	$
Nox	1.00	$	122,668	$	610	$	15,913	$
CO	1.00	$	456,063	$	(360,114)	$	324,250	$
Noise	1.00	$	2,732	$	(6,001)	$	6,418	$
Total Annual Benefits		**$**	**4,190,151**	**$**	**12,199,830**	**$**	**9,672,360**	**$**
Annual Costs								
Average Annual Private Sector Cost		**$**	0	**$**	0	**$**	0	**$**
Average Annual Public Sector Cost		**$**	591,684	**$**	1,918,576	**$**	1,289,912	**$**
Total Annual Cost		**$**	**591,684**	**$**	**1,918,576**	**$**	**1,289,912**	**$**
Benefit/Cost Comparison								
Net Benefit (Annual Benefit - Annual Cost)		**$**	**3,598,467**	**$**	**10,281,254**	**$**	**8,382,448**	**$**
B/C Ratio (Annual Benefit/Annual Cost)			**7.08**		**6.34**		**7.50**	

Table 4.7 Benefit-Cost Analysis of Highway Advisory Radio and Regional Traffic Control Systems

Benefit/Cost Summary						
Project: Austin 2			Highway Advisory Radio in Austin Area		Central Controlled Arterial Signal Coordination Systems on Lamar Blvd, 38th St., Guadalupe Blvd, 5th and 6th St.	
Benefits are reported in 2003 dollars						
Annual Benefits	**Weight**					
Change in User Mobility	1.00	$	2,983,655	$	5,444,892	$
Change In User Travel Time						
Travel Time Reliability	1.00	$		$		$
Change in Costs Paid by Users						
Fuel Costs	1.00	$		$	1,610,887	$
Non-fuel Operating Costs	1.00	$		$	832,261	$
Accident Costs (Internal Only)	1.00	$		$	2,148,986	$
Change in External Costs						
Accident Costs (External Only)	1.00	$		$	379,228	$
Emissions						
HC/ROG	1.00	$		$	104,588	$
Nox	1.00	$		$	130,190	$
CO	1.00	$		$	1,142,629	$
Noise	1.00	$		$	50,764	$
Total Annual Benefits		**$**	**2,983,655**	**$**	**11,844,446**	**$**
Annual Costs						
Average Annual Private Sector Cost		**$**	0	**$**	0	**$**
Average Annual Public Sector Cost		**$**	181,195	**$**	1,012,582	**$**
Total Annual Cost		**$**	**181,195**	**$**	**1,012,582**	**$**
Benefit/Cost Comparison						
Net Benefit (Annual Benefit - Annual Cost)		**$**	**2,802,459**	**$**	**10,831,864**	**$**
B/C Ratio (Annual Benefit/Annual Cost)			**16.47**		**11.70**	

According to the benefit-cost analysis results, it can be seen that most of the recommended ITS market packages yield positive net benefits, which makes the benefit-cost ratios greater than 1. Among those ITS market packages tested, the incident management systems (incident detection and response option) have significant benefits on reducing emissions, reducing fuel cost, and reducing accident cost (see table 4.3). The freeway control systems (central controlled ramp metering systems option) have significant impacts on user mobility, fuel cost, accident cost and emissions (see table 4.5). The central controlled arterial signal coordination systems also yield significant benefits on user mobility, user's fuel cost, operating cost, accident cost, emissions and noise (see table 4.6). However, unlike the incident management systems, freeway control systems and regional traffic control systems, the market packages of integrated transportation management/route guidance system (freeway dynamic message sign option) and broadcast traveler information systems (highway advisory radio option) only show large benefits in user mobility (see table 4.4 and 4.6). The benefits of these two market packages on environment, safety and energy consumption are not counted in IDAS.

Comparing the benefit cost ratios, it can be seen that the option of highway advisory radio has the highest benefit-cost ratio, which is 16.47. It is the relatively low cost of this option that leads to the high benefit-cost ratio. Thus, the highway advisory radio is a type of low cost ITS deployment that can bring significant user mobility benefits to the community. Therefore, in practice, the highway advisory radio option can get higher priority for deployment even though the environment benefits of this option is still unsure.

The benefit-cost ratios of the incident detection and response option vary from 0.95 to 2.59 on different freeway segments. The cost of this option is relatively higher than other ITS options, which pulls the benefit-cost ratio down. However, the incident detection and response system still yield significant net benefits on reducing emissions.

The central controlled arterial signal coordination system also shows a high benefit-cost ratio. The environmental benefits is high because the signal coordination system helps to reducing number of vehicle stops, increasing average vehicle speed, and reducing the delays, all of which contribute to reducing the emissions. Although the benefits of the central controlled arterial signal coordination system depend on the deployment scale, this option is a very good option for deployment to reduce emissions and improve traffic operations.

The central controlled ramp metering option in freeway control systems may also be a good choice to improve the traffic operations. However, in this study, this option yields both positive and negative impacts on user mobility as well as on emissions, depending on where the options are deployed. The effectiveness of this option to address the user mobility and environmental issues is unsure according to the outputs of IDAS. Therefore, in practice, this option should be carefully assessed before deployment with other methods available, for example, the dynamic traffic simulation models.

Table 4.8 gives a summary of the environmental benefits of the ITS options tested. Since the options of freeway dynamic message signs and highway advisory radios do not show environmental benefits in IDAS program, they are not included in the table.

Table 4.8 Environmental Benefits Summary of the Tested ITS Options

	HC/ROG ($)	Nox ($)	CO ($)	Total Environmental Benefits ($)	Average Annual Cost ($)	Environmental Benefits/Annual Cost Ratio
Incident Detection and Response System on IH35	102,819	267,621	1,659,755	2,030,195	1,510,538	1.34
Incident Detection and Response System on LOOP1	51,027	134,356	804,924	990,307	1,510,538	0.66
Incident Detection and Response System US183	37,708	98,622	595,999	732,329	1,510,538	0.48
Incident Detection and Response System on US71	60,937	164,586	938,842	1,164,365	1,510,538	0.77
Central Controlled Ramp Metering Systems on LOOP1	46,067	122,668	456,063	624,798	591,684	1.06
Central Controlled Ramp Metering Systems on I35	8,889	610	-360,114	-350,615	1,918,576	- 0.18
Central Controlled Ramp Metering Systems on US183	15,975	15,913	324,250	356,138	1,289,912	0.28
Central Controlled Arterial Signal Coordination Systems	104,588	130,190	1,142,629	1,377,407	1,012,582	1.36

Note: All the benefits and costs are reported in 2003 dollars.

The benefits shown in the in table 4.8 are environmental benefits only. Other benefits of the ITS options, for example, the safety benefits, user mobility benefits, and fuel consumption benefits, are excluded. However, the costs in the table are the average annual total costs. Thus, the benefit-cost ratios are calculated based on the average annual total cost and environmental benefits. The purpose of calculating the environmental benefits/cost ratios is to examine the cost-effectiveness of the recommended ITS options in reducing emissions. According to the results shown in the table above, it can be seen that central controlled arterial signal coordination systems are the most cost-effective option, which has the highest environmental benefit/cost ratio of 1.36. The performance of the incident detection and response systems is also outstanding, considering that they also bring significant benefits in safety and fuel consumption. The performance of the central controlled ramp metering systems is not stable at different deployment sites. The environmental benefit/cost ratio of this option can be as high as 1.06. However, it can also yield a negative environmental benefit/cost ratio which can be as low as -0.18.

Beside the benefit-cost ratio summary, IDAS program also estimates the performance of the ITS options tested. The user can view the performance summary of the selected ITS options relative to the baseline (without any ITS options). In IDAS program, the performance measures can be summarized either by market sectors, link facility type or link district. Table 4.9 summarizes the performance of the selected ITS options in emissions reduction. The incident detection and response systems and central controlled arterial signal coordination systems are our main concern.

Table 4.9 Performance Summary of Selected ITS Options

	Daily Change of Total Emissions in the Whole Study Area (tons (%))		
	Hydrocarbon Emissions	Carbon Monoxide Emissions	Nitrous Oxide Emissions
Incident Detection and Response System on IH35	-0.16(-0.2%)	-1.20(-0.3%)	-0.20(-0.2%)
Incident Detection and Response System on LOOP1	-0.08(-0.1%)	-0.58(-0.2%)	-0.10(-0.1%)
Incident Detection and Response System US183	-0.10(-0.1%)	-0.68(-0.2%)	-0.12(-0.2%)
Incident Detection and Response System on US71	-0.06(-0.1%)	-0.43(-0.1%)	-0.07(-0.1%)
Central Controlled Arterial Signal Coordination Systems	-0.17(-0.2%)	-0.82(-0.2%)	-0.10(-0.1%)

As shown in the table, the daily changes in the total amount of emissions due to ITS improvements are summarized. The absolute value of the amount of the emissions and the percentage of the difference are calculated. For example, the incident detection and response systems deployed on IH35 may reduce 1.20 tons of traffic-generated carbon monoxide emissions every day, which causes a 0.3% reduction of the total carbon monoxide emissions in the whole study area. As described in chapter 3, in the whole study area, the total daily amount of carbon monoxide emissions generated by traffic is about 346.2 tons.

Since the percentages of difference/improvement are calculated on the basis of the total daily amount of emissions generated by traffic in the whole study area, which is a large denominator, the percentages are not high. However, considering that the ITS options are only deployed on a short freeway/expressway segment or in a small region, the absolute values of the emissions reduction are still significant.

4.4 RECOMMENDATIONS FOR ITS EVALUATIONS AND DEPLOYMENTS

According to the evaluation results already discussed, some recommendations can be made for the evaluations and deployments of ITS market packages.

First of all, the case study completed in this study indicates that the four-step method proposed at the beginning of this chapter works very well for regional ITS planning and evaluation. The four-step method, which is developed on the basis of FHWA ITS planning process Version 2.1, integrates emissions modeling techniques, Geographic Information System, National ITS Architecture, Intelligent Transportation System Deployment Analysis System and our knowledge of ITS benefits into a comprehensive process for developing ITS solutions to address the mobile-source emissions problems in a metropolitan area. Moreover, this method can be expanded for developing ITS strategies for safety and mobility objectives. The same idea can be applied.

Second, the GIS program and IDAS program employed in this method can share the same data inputs, which brings great convenience to the analysis. Based to our experience, the outputs from the urban transportation planning model, which is developed with TransCAD model, are highly recommended. The transportation network from TransCAD and the traffic characteristics it carries on can be imported to not only GIS, but also IDAS.

Third, it is found that the market packages of Incident Management System, Regional Traffic Control and Emissions and Environmental Hazard Sensing have high benefits on emissions reduction. According the evaluation outputs from IDAS program, the Incident Management Systems and Regional Traffic Control Systems are outstanding market packages for emissions reduction. They are both cost-effective. Therefore, in practice, these two market packages can get higher priority for deployments. On the other hand, although Environmental Hazard Sensing market package cannot be evaluated in the IDAS program, it should also get the higher priority for deployments because of its direct benefits to air quality.

Finally, the market packages of Freeway Control, Integrated Transportation Management/Route Guidance and Broadcast Traveler Info may have moderate benefits on emissions reduction. The IDAS experiments show that the highway advisory radio and freeway dynamic message signs can yield significant benefits on user mobility. However, the environmental benefits of these two ITS options are not counted in IDAS. These two options can bring indirect benefits by increasing user mobility. So, the highway advisory radio and freeway dynamic message signs are also recommended for deployments. As for Freeway Control market package, IDAS program shows that the performance of the central controlled ramp metering option is not very stable. It can bring positive or negative impacts to the traffic operations. Since the IDAS program does not have sub-module to optimize the ramp metering deployments, it may not be a good tool to assess the ramp metering option. If ramp metering option is considered for deployments, some other evaluation methods or programs is very necessary.

In summary, following the four-step method suggested in this study, the ITS strategies for implementation to reduce emissions are recommended as below:

1. Traffic Management Center — TMC is not discussed in the experiments. However, a TMC is very necessary to integrate and manage all the ITS deployments. The scale and benefits of the TMC depend on the size of the transportation system it manages.
2. The Incident Management Systems — The recommendation is to deploy incident detection and response system along the major corridors;
3. Regional Traffic Control — The recommendation is to deploy signal coordination system along major arterials;
4. Environmental Hazard Sensing — The recommendation is to set up air quality monitoring stations and establish communication links between these stations and the traffic management center;

These four market packages are recommended for implementation with highest priority for emissions reduction purpose.

1. Broadcast Traveler Info — The recommendation is to set up the highway advisory radio station and broadcast the real-time traffic information to drivers.
2. Integrated Transportation Management/Route Guidance — The recommendation is to deploy central controlled freeway dynamic message signs and deliver relevant real-time traffic information to drivers.

These two ITS market packages are recommended with high priority because they can bring indirect environmental benefits.

Recommendations are not made on freeway control systems. As for rap metering, further study on the impact analysis of this strategy is very necessary.

CHAPTER 5. CONCLUSIONS

The overall objective of this study was to develop a Geographic Information System (GIS) framework to estimate the mobile-source emissions in a metropolitan area and examine the potential benefits of Intelligent Transportation Systems (ITS) strategies in emissions reduction. First, a review of the literature in related to emissions modeling, application of GIS in transportation modeling, and ITS evaluation and planning was provided, to serve as the foundation for this study. Then, based on the GIS emissions estimation model, the ITS strategies to reduce mobile emissions were proposed and their effectiveness were examined with ITS Deployment Analysis System (IDAS) program. A concise four-step method was suggested to develop the ITS solutions to reduce mobile-source emissions. Following the four-step method, it was determined that the market packages of Incident Management System, Regional Traffic Control, Environmental Hazard Sensing, Integrated Transportation Management/Route Guidance and Broadcast Traveler Info were cost-effective ITS strategies to reduce emissions. Among them, the Incident Management System, Regional Traffic Control and Environmental Hazard Sensing were recommended for deployments with the highest priority. The Integrated Transportation Management/Route Guidance and Broadcast Traveler Info packages were recommended for deployments with high priority.

A case study was completed with the transportation system of Austin, TX. The four-step method proposed in this study has been proved to be a successful method to develop ITS solutions to address the mobile-source emissions problem. The first step is to estimate the mobile-source emissions from current transportation system and identify the problems. To model the emissions, MOBILE6.0 model was used derive the emission rates. The vehicles registered in Austin area were classified into 5 categories. The emissions were then estimated on the basis of vehicle speed, vehicle type, emission rates, and traffic volume. The road segments with high pollutant concentration rates were highlighted. Next, to address the problems defined in the first step, various ITS market packages are screened under the guidance of the national ITS architecture. Previous studies, especially the field tests already completed throughout the United States, are taken as a very important supplement to the ITS market packages screening method. Then, the suggested ITS market packages and options are pre-evaluated. To evaluate the ITS market packages and options, IDAS program is used to attempt to analyze the potential benefits of deploying these ITS market packages. Most of the suggested ITS market packages can be examined except the Environmental hazard Sensing. Finally, The evaluation results are compared and the recommendations for ITS implementation are made.

Through this study, it was noticed that the software packages used for analysis, which were GIS and IDAS, had great compatibility in using the same data inputs. The two programs' capability of sharing the same inputs brought lots of convenience to performing this study. The outputs of the urban transportation planning (UTP) model can meet the data requirement for the basic analysis in this study. The UTP model developed within TransCAD is preferred as the data source. Aside from the results of the impact analysis in this research, the IDAS program appears as if it could be used as starting point for ITS benefits and impacts analysis purpose.

Finally, it is recommended that the framework of four-step method can be extended to the research on developing ITS strategies to improve safety, mobility, etc. The future related research should also consider other programs available to pre-evaluate the ITS strategies, for example, the dynamic traffic assignment programs. Also, the concise four-step method can be refined by using new analysis tools or through modifications of existing ones.

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APPENDIX A

TABLE 1 CO Emission Factors Derived from MOBILE6.0 model:

Pollutant	Cal. Year	Speed	LDGV ef	LDGT1 ef	LDDV ef	LDDT ef	HDDV ef	All Veh
CO	2002	2.5	96.755	109.477	4.566	4.983	35.198	**97.189**
CO	2002	3	82.16	93.089	4.38	4.78	33.767	**83.408**
CO	2002	4	63.916	72.484	4.037	4.406	31.12	**65.933**
CO	2002	5	52.97	60.055	3.727	4.068	28.733	**55.237**
CO	2002	6	45.672	51.748	3.448	3.762	26.577	**47.967**
CO	2002	7	40.46	45.811	3.195	3.486	24.628	**42.679**
CO	2002	8	36.55	41.36	2.966	3.237	22.863	**38.646**
CO	2002	9	33.509	37.903	2.758	3.01	21.264	**35.461**
CO	2002	10	31.077	35.142	2.57	2.805	19.812	**32.876**
CO	2002	11	29.087	32.887	2.399	2.618	18.493	**30.735**
CO	2002	12	27.428	31.01	2.243	2.448	17.294	**28.931**
CO	2002	13	26.025	29.425	2.102	2.294	16.201	**27.389**
CO	2002	14	24.822	28.068	1.972	2.153	15.205	**26.056**
CO	2002	15	23.779	26.892	1.855	2.024	14.297	**24.892**
CO	2002	16	22.867	25.864	1.747	1.906	13.467	**23.867**
CO	2002	17	22.062	24.956	1.649	1.799	12.709	**22.957**
CO	2002	18	21.347	24.148	1.559	1.701	12.015	**22.146**
CO	2002	19	20.707	23.423	1.476	1.611	11.379	**21.416**
CO	2002	20	19.851	22.579	1.401	1.529	10.797	**20.538**
CO	2002	21	18.806	21.505	1.331	1.453	10.264	**19.493**
CO	2002	22	17.856	20.526	1.268	1.384	9.774	**18.543**
CO	2002	23	16.989	19.63	1.21	1.32	9.325	**17.674**
CO	2002	24	16.194	18.807	1.156	1.262	8.912	**16.878**
CO	2002	25	15.463	18.048	1.107	1.208	8.534	**16.146**
CO	2002	26	14.787	17.346	1.062	1.159	8.186	**15.47**
CO	2002	27	14.162	16.695	1.021	1.114	7.867	**14.845**
CO	2002	28	13.582	16.089	0.983	1.072	7.574	**14.266**
CO	2002	29	13.042	15.524	0.948	1.034	7.305	**13.727**
CO	2002	30	12.537	14.996	0.916	0.999	7.059	**13.226**
CO	2002	31	12.065	14.502	0.886	0.967	6.833	**12.758**
CO	2002	32	11.623	14.039	0.86	0.938	6.627	**12.321**
CO	2002	33	11.207	13.605	0.835	0.911	6.438	**11.912**
CO	2002	34	10.816	13.196	0.813	0.887	6.267	**11.529**
CO	2002	35	10.448	12.811	0.793	0.865	6.111	**11.169**
CO	2002	36	10.099	12.449	0.774	0.845	5.969	**10.831**
CO	2002	37	9.77	12.107	0.758	0.827	5.842	**10.514**
CO	2002	38	9.458	11.784	0.743	0.811	5.728	**10.215**
CO	2002	39	9.162	11.478	0.73	0.796	5.626	**9.933**
CO	2002	40	8.88	11.189	0.718	0.784	5.536	**9.668**
CO	2002	41	8.613	10.915	0.708	0.773	5.458	**9.418**
CO	2002	42	8.358	10.656	0.699	0.763	5.39	**9.181**

TABLE 1 CO Emission Factors Derived from MOBILE6.0 model (Continued)

CO	2002	43	8.115	10.409	0.692	0.755	5.333	**8.959**
CO	2002	44	7.883	10.175	0.686	0.748	5.286	**8.748**
CO	2002	45	7.661	9.952	0.681	0.743	5.249	**8.55**
CO	2002	46	7.449	9.74	0.677	0.739	5.222	**8.363**
CO	2002	47	7.247	9.537	0.675	0.737	5.204	**8.186**
CO	2002	48	7.052	9.342	0.674	0.736	5.196	**8.019**
CO	2002	49	7.052	9.342	0.674	0.736	5.198	**8.026**
CO	2002	50	7.052	9.342	0.676	0.737	5.208	**8.035**
CO	2002	51	7.052	9.342	0.678	0.74	5.229	**8.047**
CO	2002	52	7.052	9.342	0.682	0.744	5.259	**8.062**
CO	2002	53	7.052	9.342	0.687	0.75	5.299	**8.079**
CO	2002	54	7.052	9.342	0.694	0.757	5.349	**8.1**
CO	2002	55	7.052	9.342	0.702	0.766	5.409	**8.123**
CO	2002	56	7.842	10.494	0.711	0.776	5.48	**8.954**
CO	2002	57	8.633	11.645	0.721	0.787	5.562	**9.788**
CO	2002	58	9.423	12.797	0.734	0.801	5.655	**10.626**
CO	2002	59	10.214	13.948	0.747	0.815	5.76	**11.468**
CO	2002	60	11.004	15.1	0.763	0.832	5.878	**12.313**
CO	2002	61	11.795	16.251	0.78	0.851	6.01	**13.163**
CO	2002	62	12.585	17.402	0.798	0.871	6.155	**14.018**
CO	2002	63	13.376	18.554	0.819	0.894	6.316	**14.877**
CO	2002	64	14.166	19.705	0.842	0.919	6.493	**15.742**
CO	2002	65	14.957	20.857	0.867	0.947	6.686	**16.613**

TABLE 2 HC Emission Factors Derived from MOBILE6.0 model

ollutant	Cal. Year	Speed	LDGV ef	LDGT1 ef	LDDV ef	LDDT ef	HDDV ef	All Veh
HC	2011	2.5	13.508	15.125	1.096	1.497	4.551	**13.454**
HC	2011	3	10.42	11.701	1.067	1.458	4.432	**10.484**
HC	2011	4	7.109	8.015	1.013	1.384	4.208	**7.287**
HC	2011	5	5.416	6.12	0.963	1.315	3.999	**5.64**
HC	2011	6	4.41	4.99	0.916	1.251	3.803	**4.65**
HC	2011	7	3.751	4.247	0.872	1.191	3.62	**3.994**
HC	2011	8	3.39	3.826	0.831	1.135	3.449	**3.623**
HC	2011	9	3.117	3.509	0.792	1.082	3.289	**3.339**
HC	2011	10	2.896	3.254	0.756	1.033	3.139	**3.107**
HC	2011	11	2.713	3.044	0.722	0.986	2.999	**2.913**
HC	2011	12	2.558	2.868	0.69	0.943	2.867	**2.747**
HC	2011	13	2.425	2.718	0.661	0.903	2.744	**2.604**
HC	2011	14	2.309	2.589	0.633	0.864	2.628	**2.478**
HC	2011	15	2.206	2.476	0.607	0.829	2.519	**2.367**
HC	2011	16	2.115	2.376	0.582	0.795	2.417	**2.268**
HC	2011	17	2.032	2.287	0.559	0.764	2.321	**2.179**
HC	2011	18	1.957	2.208	0.537	0.734	2.231	**2.097**
HC	2011	19	1.889	2.136	0.517	0.706	2.147	**2.023**
HC	2011	20	1.813	2.057	0.498	0.68	2.067	**1.944**
HC	2011	21	1.741	1.981	0.48	0.655	1.992	**1.869**
HC	2011	22	1.675	1.913	0.463	0.632	1.921	**1.8**
HC	2011	23	1.615	1.85	0.447	0.61	1.855	**1.737**
HC	2011	24	1.56	1.792	0.432	0.59	1.792	**1.679**
HC	2011	25	1.509	1.739	0.417	0.57	1.733	**1.626**
HC	2011	26	1.462	1.69	0.404	0.552	1.678	**1.577**
HC	2011	27	1.419	1.644	0.391	0.535	1.625	**1.531**
HC	2011	28	1.378	1.602	0.38	0.518	1.576	**1.488**
HC	2011	29	1.34	1.562	0.368	0.503	1.53	**1.448**
HC	2011	30	1.304	1.525	0.358	0.489	1.486	**1.411**
HC	2011	31	1.271	1.491	0.348	0.475	1.445	**1.375**
HC	2011	32	1.239	1.458	0.339	0.462	1.406	**1.343**
HC	2011	33	1.209	1.427	0.33	0.45	1.369	**1.312**
HC	2011	34	1.181	1.399	0.321	0.439	1.335	**1.282**
HC	2011	35	1.155	1.371	0.314	0.428	1.302	**1.255**
HC	2011	36	1.13	1.345	0.306	0.418	1.272	**1.229**
HC	2011	37	1.106	1.321	0.299	0.409	1.243	**1.204**
HC	2011	38	1.083	1.298	0.293	0.4	1.216	**1.18**
HC	2011	39	1.061	1.276	0.287	0.392	1.19	**1.158**
HC	2011	40	1.041	1.255	0.281	0.384	1.166	**1.137**
HC	2011	41	1.021	1.235	0.276	0.376	1.144	**1.117**
HC	2011	42	1.002	1.215	0.27	0.369	1.123	**1.097**
HC	2011	43	0.984	1.197	0.266	0.363	1.104	**1.079**
HC	2011	44	0.966	1.18	0.261	0.357	1.085	**1.061**

TABLE 2 HC Emission Factors Derived from MOBILE6.0 model (Continued)

HC	2011	45	0.95	1.163	0.257	0.351	1.068	**1.045**
HC	2011	46	0.934	1.147	0.253	0.346	1.052	**1.029**
HC	2011	47	0.918	1.131	0.25	0.341	1.038	**1.013**
HC	2011	48	0.903	1.116	0.247	0.337	1.024	**0.998**
HC	2011	49	0.898	1.111	0.244	0.333	1.012	**0.992**
HC	2011	50	0.893	1.105	0.241	0.329	1	**0.986**
HC	2011	51	0.888	1.1	0.238	0.325	0.989	**0.981**
HC	2011	52	0.884	1.095	0.236	0.322	0.98	**0.976**
HC	2011	53	0.88	1.091	0.234	0.32	0.971	**0.971**
HC	2011	54	0.876	1.087	0.232	0.317	0.964	**0.966**
HC	2011	55	0.872	1.083	0.23	0.315	0.957	**0.962**
HC	2011	56	0.888	1.099	0.229	0.313	0.951	**0.976**
HC	2011	57	0.905	1.117	0.228	0.311	0.946	**0.99**
HC	2011	58	0.922	1.134	0.227	0.31	0.942	**1.005**
HC	2011	59	0.939	1.151	0.226	0.309	0.939	**1.02**
HC	2011	60	0.956	1.169	0.225	0.308	0.936	**1.035**
HC	2011	61	0.973	1.187	0.225	0.307	0.934	**1.05**
HC	2011	62	0.99	1.205	0.225	0.307	0.934	**1.066**
HC	2011	63	1.008	1.223	0.225	0.307	0.934	**1.081**
HC	2011	64	1.026	1.241	0.225	0.307	0.934	**1.097**
HC	2011	65	1.043	1.259	0.225	0.308	0.936	**1.113**

TABLE 3 NOx Emission Factors Derived from MOBILE6.0 model

Pollutant	**Cal. Year**	**SPEED**	**LDGV ef**	**LDGT1 ef**	**LDDV ef**	**LDDT ef**	**HDDV ef**	**All Veh**
NOx	2007	2.5	1.88	2.152	1.907	2.107	10.915	**2.622**
NOx	2007	3	1.759	2.013	1.866	2.061	10.677	**2.494**
NOx	2007	4	1.608	1.84	1.787	1.974	10.228	**2.326**
NOx	2007	5	1.517	1.736	1.714	1.894	9.811	**2.216**
NOx	2007	6	1.457	1.667	1.647	1.819	9.424	**2.135**
NOx	2007	7	1.414	1.618	1.584	1.75	9.066	**2.073**
NOx	2007	8	1.381	1.581	1.526	1.686	8.733	**2.022**
NOx	2007	9	1.356	1.552	1.472	1.626	8.425	**1.98**
NOx	2007	10	1.336	1.529	1.422	1.571	8.139	**1.944**
NOx	2007	11	1.319	1.51	1.376	1.52	7.875	**1.912**
NOx	2007	12	1.306	1.494	1.333	1.472	7.629	**1.885**
NOx	2007	13	1.294	1.481	1.293	1.429	7.402	**1.86**
NOx	2007	14	1.284	1.469	1.257	1.388	7.191	**1.839**
NOx	2007	15	1.275	1.459	1.223	1.35	6.997	**1.819**
NOx	2007	16	1.268	1.451	1.191	1.316	6.817	**1.802**
NOx	2007	17	1.261	1.443	1.162	1.284	6.652	**1.786**
NOx	2007	18	1.255	1.436	1.136	1.255	6.5	**1.772**
NOx	2007	19	1.25	1.43	1.111	1.228	6.36	**1.759**
NOx	2007	20	1.253	1.422	1.089	1.203	6.232	**1.752**
NOx	2007	21	1.261	1.424	1.069	1.18	6.116	**1.751**
NOx	2007	22	1.268	1.427	1.05	1.16	6.01	**1.751**
NOx	2007	23	1.275	1.429	1.033	1.141	5.914	**1.751**
NOx	2007	24	1.281	1.431	1.018	1.125	5.828	**1.751**
NOx	2007	25	1.287	1.432	1.005	1.11	5.752	**1.751**
NOx	2007	26	1.292	1.434	0.993	1.097	5.684	**1.752**
NOx	2007	27	1.297	1.436	0.983	1.086	5.626	**1.753**
NOx	2007	28	1.301	1.437	0.974	1.076	5.575	**1.754**
NOx	2007	29	1.306	1.438	0.967	1.068	5.534	**1.756**
NOx	2007	30	1.31	1.44	0.961	1.062	5.5	**1.758**
NOx	2007	31	1.313	1.441	0.957	1.057	5.474	**1.76**
NOx	2007	32	1.317	1.442	0.953	1.053	5.456	**1.763**
NOx	2007	33	1.32	1.443	0.952	1.051	5.446	**1.766**
NOx	2007	34	1.323	1.444	0.951	1.051	5.444	**1.77**
NOx	2007	35	1.326	1.445	0.952	1.052	5.449	**1.774**
NOx	2007	36	1.328	1.445	0.955	1.054	5.462	**1.778**
NOx	2007	37	1.331	1.446	0.958	1.058	5.483	**1.783**
NOx	2007	38	1.333	1.447	0.963	1.064	5.512	**1.788**
NOx	2007	39	1.336	1.448	0.97	1.071	5.549	**1.794**
NOx	2007	40	1.338	1.448	0.978	1.08	5.594	**1.8**
NOx	2007	41	1.34	1.449	0.987	1.09	5.648	**1.806**
NOx	2007	42	1.342	1.45	0.998	1.102	5.71	**1.813**
NOx	2007	43	1.344	1.45	1.01	1.116	5.781	**1.821**
NOx	2007	44	1.346	1.451	1.024	1.131	5.861	**1.829**
NOx	2007	45	1.347	1.451	1.04	1.149	5.95	**1.838**

TABLE 3 NOx Emission Factors Derived from MOBILE6.0 model (Continued)

NOx	2007	46	1.349	1.452	1.057	1.168	6.05	**1.847**
NOx	2007	47	1.351	1.452	1.076	1.189	6.16	**1.857**
NOx	2007	48	1.352	1.453	1.098	1.212	6.281	**1.868**
NOx	2007	49	1.392	1.508	1.121	1.238	6.414	**1.918**
NOx	2007	50	1.432	1.563	1.146	1.266	6.558	**1.969**
NOx	2007	51	1.473	1.618	1.174	1.296	6.716	**2.021**
NOx	2007	52	1.513	1.672	1.203	1.329	6.886	**2.074**
NOx	2007	53	1.553	1.727	1.236	1.365	7.072	**2.128**
NOx	2007	54	1.593	1.782	1.271	1.404	7.272	**2.182**
NOx	2007	55	1.633	1.837	1.309	1.446	7.489	**2.238**
NOx	2007	56	1.674	1.892	1.35	1.491	7.724	**2.295**
NOx	2007	57	1.714	1.947	1.394	1.54	7.977	**2.353**
NOx	2007	58	1.754	2.002	1.442	1.592	8.25	**2.413**
NOx	2007	59	1.794	2.057	1.493	1.649	8.544	**2.474**
NOx	2007	60	1.834	2.112	1.548	1.71	8.862	**2.536**
NOx	2007	61	1.875	2.167	1.608	1.776	9.204	**2.601**
NOx	2007	62	1.915	2.222	1.673	1.848	9.573	**2.667**
NOx	2007	63	1.955	2.276	1.742	1.925	9.971	**2.734**
NOx	2007	64	1.995	2.331	1.817	2.007	10.401	**2.804**
NOx	2007	65	2.035	2.386	1.898	2.097	10.864	**2.877**