THE USE OF PERFORMANCE MEASUREMENT TO INCORPORATE AIR QUALITY GOALS INTO MILEAGE-BASED USER FEES

A Thesis

by

KRISTEN WALLIN NOVAK

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	Mark Burris
Committee Members,	Josias Zietsman
	Dominique Lord
Head of Department,	Robin Autenrieth

May 2017

Major Subject: Civil Engineering

ABSTRACT

The goal of this research was to develop a mileage-based user fee (MBUF) system that incorporated air quality goals through the use of performance measurement. A framework of performance measures was developed that addresses multiple aspects of transportation which affect air quality. In this research, performance measures were selected that relate travel to the emission of air pollutants. Better performance would contribute to achievement of objectives, which would in turn contribute to achievement of air quality and energy goals.

Performance measures included aspects of driver behavior and characteristics of the vehicle being driven. Average vehicle characteristics were used to determine base emission rates for five pollutant types, which were scaled to reflect characteristics on an individual's vehicle. Driving behaviors were translated to changes in emissions based on emissions software modeling. Based on these results, base emission rates were adjusted to reflect an individual's performance in terms of driving behaviors and vehicle type. A performance score was then determined for each pollutant type by comparing the scaled emission rates to anticipated rates across the population. These performance scores were then aggregated into a final score. To determine the actual mileage fee assessed to an individual, the resulting final performance score and system-level average score were used. An example of the performance measurement framework and pricing system was provided through a small case study. Use of transportation elasticity values was demonstrated to relate desired mileage changes to required changes in pricing. A decrease in mileage would have a direct decrease in the amount of pollutants emitted.

Air quality concerns are one policy goal that has the potential to be included as an important part in any road-pricing system. While such goals are not currently given priority in mileage-based pricing pilot studies, the framework developed in this research illustrates how air quality could be included in pricing attempts in the future. With any mileage-based fee system, extensive public outreach and education would be vital to implementation, and use of a pilot program would be recommended. Mileage driven

would likely decrease in response to pricing, and over time the vehicle fleet will improve as well. Consideration must be given to equity concerns, as lower-income drivers may have more difficulty changing driving patterns or purchasing better vehicles. Finally, policy-makers would have to determine the extent of data desired. Increased data would help to address air quality goals, but the benefit of improved data would have to be weighed against the cost of obtaining it.

ACKNOWLEDGEMENTS

The research presented in this thesis is a part of a project conducted by the Texas A&M Transportation Institute (TTI) as part of the University Transportation Center for Mobility (UTCM). I would like to thank Dr. Joe Zietsman and Dr. Reza Farzaneh for the opportunity to work on this project as a Graduate Assistant Researcher. It has been a privilege working for both Dr. Zietsman and Dr. Farzaneh, along with all the TTI staff in College Station and in Austin.

I would like to thank the chair of my thesis committee, Dr. Mark Burris, for his tremendous contribution to the development of my thesis proposal and thesis. Dr. Burris spent much time reviewing my written material and offering invaluable insight and suggestions. I would also like to thank the members of my thesis committee, Dr. Joe Zietsman and Dr. Dominique Lord, for all their comments and suggestions that helped me strengthen my final thesis.

Finally, I wish to thank my family, friends, coworkers, and especially my husband, Dominic, for their love, support, and patience.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Professor Mark Burris (advisor) and Professor Dominique Lord of the Department of Civil Engineering and Dr. Joe Zietsman of the Environment and Air Quality Division of the Texas A&M Transportation Institute (TTI).

All work for the thesis was completed by the student, in collaboration with Dr. Reza Farzaneh, Richard Baker, and Ginger Goodin of the Texas A&M Transportation Institute. Vehicle travel data utilized for the analysis of speed and acceleration presented in Section 4 was obtained by TTI employees. Vehicle travel data analyzed as part of the case study presented in Section 7 was also obtained by TTI employees.

All other work conducted for the thesis was completed by the student independently.

Funding Sources

This work was made possible in part by the U.S. Department of Transportation Research and Innovative Technology Administration under Grant Number DTRT06-G-0044. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the U.S. DOT.

NOMENCLATURE

AFV	Alternative Fuel Vehicle
ALVW	Adjusted Loaded Vehicle Weight, average of empty weight and GVWR
CFC	Chlorofluorocarbon
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DOT	Department of Transportation
E85	Blend of 85% denatured ethanol fuel and gasoline
EPA	Environmental Protection Agency
ESAL	Equivalent Single Axle Load
GHG	Greenhouse Gas
GPS	Global Positioning System
GVWR	Gross Vehicle Weight Rating, maximum fully loaded vehicle weight
g/mi	grams per mile
HC	Hydrocarbon
HCHO	Formaldehyde
HLDT	Heavy Light-Duty Trucks, a truck between 6001 and 8500 pounds GVWR
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
IH	Interstate Highway
IRIS	Integrated Risk Information System
LDV	Light-Duty Vehicle, or passenger car
LDT	Light-Duty Truck, a truck up to 8500 pounds GVWR
LDT1	Light-Duty Truck 1, a LLDT up to 3750 pounds LVW
LDT2	Light-Duty Truck 2, a LLDT between 3751 and 5750 pounds LVW
LDT3	Light-Duty Truck 3, a HLDT between 3751 and 5750 pounds ALVW
LDT4	Light-Duty Truck 4, a HLDT over 5750 pounds ALVW

LLDT	Light Light-Duty Truck, a truck up to 6000 pounds GVWR
LVW	Loaded Vehicle Weight, nominal empty vehicle weight plus 300 pounds
MBUF	Mileage-Based User Fee
MDPV	Medium-Duty Passenger Vehicle, a truck between 8501 and 10,000 pounds GVWR
MOVES	MOtor Vehicle Emission Simulator
MSAT	Mobile Source Air Toxic
NAAQS	National Ambient Air Quality Standards
NHTSA	National Highway Traffic Safety Administration
NMOG	Non-Methane Organic Gas
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
O_2	Oxygen Gas Molecule (Dioxygen)
O_3	Ozone
OBU	On-Board Unit
PAYD	Pay-As-You-Drive
PEMS	Portable Emissions Measurement System
PM	Particulate Matter
$PM_{2.5}$	fine” particles with diameters less than or equal to 2.5 micrometers
PM_{10}	particles with diameters less than or equal to 10 micrometers and greater than 2.5
R^2	represents the coefficient of determination
SIP	State Implementation Plan
SO_2	Sulfur Dioxide
THC	Total Hydrocarbons
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLE Page

1. INTRODUCTION

1.1: Background

Air quality has become an important consideration both nationally and worldwide. In addition to the six criteria pollutants covered by the National Ambient Air Quality Standards (NAAQS), other emissions such as air toxics and greenhouse gases (GHGs) are cause for concern (*1*). Air pollution negatively impacts the environment, contributing to phenomenon such as acidification and global climate change. In addition, air pollution has a negative impact on human health. It is believed that as many as six out of ten Americans reside in areas with unhealthy levels of air pollution (*2*). Between 50 and 60 percent of the air pollution in the United States is attributed to transportation, both on- and off-road (*3*). Within the transportation sector emissions are considered a negative externality, in that the cost associated with poor air quality is borne by society as a whole, rather than just the users of the transportation system.

One potential method of addressing costs associated with transportation externalities is to internalize those costs, potentially through implementation of a system of vehicle mileage fees. Mileage-based user fees (MBUFs) are currently being researched as a solution to transportation funding problems and as a possible replacement of the fuel tax. Pricing has also been used to address problems such as congestion. However, using these fees to address other goals, such as environmental mitigation and social equity, has not been fully explored. The application of MBUFs to address air quality problems will be studied in this research. To achieve air quality goals with MBUFs, a system of performance measures will be created to relate fees to vehicle and driver performance. In other words, fees should be established in such a way as to encourage better performance as it related to vehicle emissions.

1.2: Research Motivation

Mileage-based user fees are currently one of the leading pricing mechanisms being studied as a potential replacement for the traditional fuel tax. In addition to alleviating long-term transportation funding concerns, MBUFs can be used to address various policy goals. For example, congestion pricing is one system that can be mileage-based (such as Interstate 15 in San Diego) and generally attempts to shift travel to off-peak periods. However, while congestion pricing may result in reduced emissions, the focus of the system is not to improve air quality. In fact, the use of MBUFs to achieve policy goals other than revenue and congestion mitigation has not yet received much attention. For example, environmental or equity considerations have rarely been incorporated into the pricing scheme.

Therefore, this research represents an initial step towards the incorporation of air quality goals within mileage-based pricing. Performance measurement will be used to address potential policy goals and objectives related to air quality. An initial set of goals includes:

1. Reducing pollutant emissions;
2. Reducing greenhouse gas emissions;
3. Reducing negative impacts on human health; and
4. Reducing negative impacts on the environment.

While the goal set includes four goals overall, the first two represent main goals and the other two represent sub-goals, which relate to the main goals. Addressing the main goals of reducing pollutant and greenhouse gas emissions would also simultaneously address the sub-goals of reducing negative impacts on health and the environment.

1.3: Research Objectives

The overall goal of this research is the development of a methodology through which mileage-based user fees can be utilized to address air quality impacts of transportation. Performance measurement will be used to quantify air quality impacts for use in pricing. The research objectives include:

- To identify potential goals and objectives of mileage-based user fees as they relate to transportation emissions;

- To develop a framework of performance measures that can be used to address these goals and objectives;
- To identify the data needed to quantify each measure, as well as robust data sources and collection methods;
- To develop an index that will aggregate performance results for use in developing the appropriate user fee;
- To identify and evaluate a methodology by which a MBUF system could be applied based on performance; and
- To evaluate the methodology through application in a case study.

1.4: Research Methodology

The following is a summary of the different tasks carried out as part of this research:

1.4.1: Task 1—Literature Review

While important concepts were briefly touched upon in the introductory section, a much more detailed review of related concepts was conducted. As outlined in the introduction, performance measurement, transportation emissions, and MBUFs are the primary subjects of interest for this research. In addition to existing literature, current transportation agency practices were reviewed, especially as they pertain to air quality-related performance measures. National and international user fee pricing initiatives were also included in the review. In addition to providing a background for the research, the literature review provides guidance on desirable goals, objectives, and performance measures. Potential data sources, evaluation techniques, and indexing strategies were investigated for future tasks. Finally, monetization methods were identified in literature to provide a basis for a pricing scheme.

1.4.2: Task 2—Selection of Performance Measures and Development of Measurement Framework

Information obtained through the literature review was used to develop the initial set of overall goals, or guiding principles, related to air quality. The set of goals describes the desired outcome of the mileage-based user fee system. An initial set of objectives was then developed to further define the goals as they relate to transportation, as discussed above. Some objectives may address multiple goals. Finally, potential performance measures will be identified for each objective, based primarily on the literature review.

1.4.3: Task 3—Identify Data Needs for Selected Measures and Aggregation Techniques

The set of measures will be refined based on input from experts in air quality and in road pricing at the Texas A&M Transportation Institute. Selection of measures will likely relate primarily to robustness and applicability to user fees. Furthermore, sources of data and collection procedures will need to be identified for each measure. Thus, the measure set may be further refined based on data availability or reliability. For example, some measures may be very applicable and useful, but technology necessary to collect the data for the measure may currently not exist.

In addition, methods for aggregating performance data should be identified and evaluated. Aggregation of performance would result in a final overall indicator of performance, which could be used to determine the appropriate user fee.

1.4.4: Task 4—Develop a Mileage-Based User Fee System Based on the Measurement Framework

A methodology for establishing appropriate user fees will be developed. The purpose of the MBUF system is to attempt to use monetary means to achieve established air quality goals. In this case, the per-mile fee charged to each individual in the system will depend on the relative performance of that particular vehicle and driver. Thus, drivers would have a financial incentive to change their travel behavior or aspects of their vehicle, as improved performance would result in a lower fee. There would also be a financial incentive to drive fewer miles, since the fee would be charged for each mile traveled. The desirable outcome is that there will be a cumulative affect across the transportation system as behavior and vehicles change, resulting in fewer emissions and a smaller air quality impact. In this way, the pricing scheme is used to meet the goals. Therefore, pricing should take transportation elasticities into consideration. Such elasticities relate anticipated changes in behavior to changes in cost. Then, if a specific goal were established, such as a goal to reduce emissions by a specified amount during a certain time period, pricing could be adjusted so that the necessary change in behavior could be achieved. Such a process is illustrated in Figure 1.1.

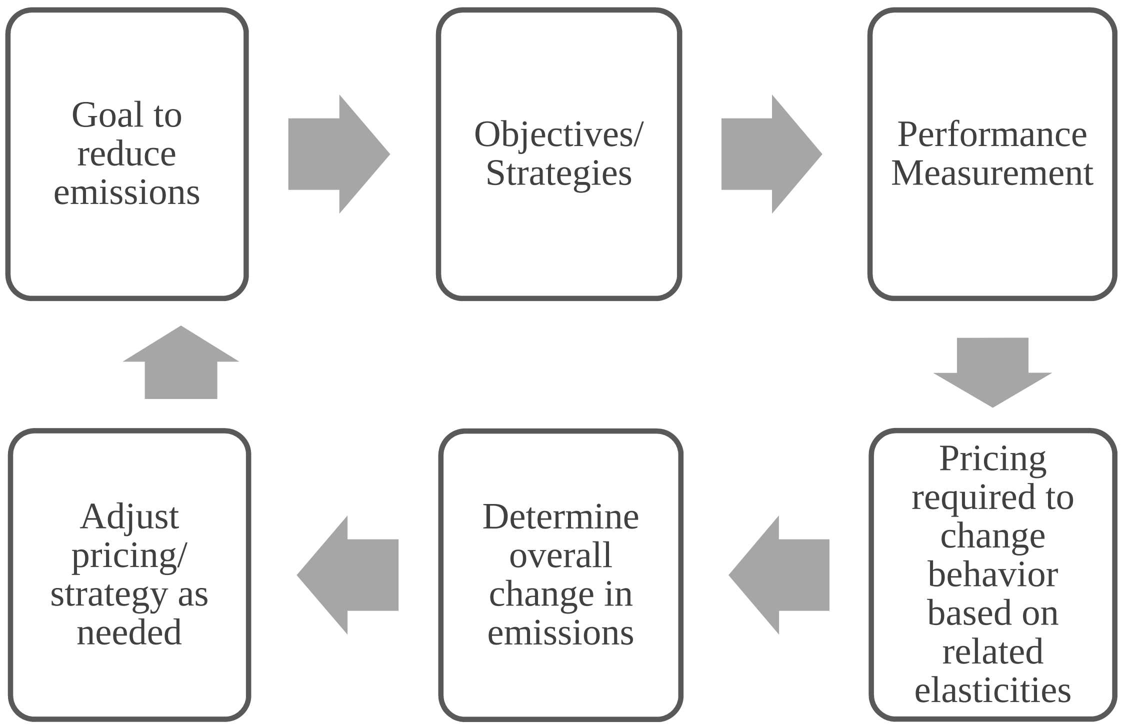

Figure 1.1: Pricing process to achieve goals.

As shown, the process would require feedback so that pricing can be adjusted as needed. In addition to elasticities associated with various performance aspects, the relative effect of each measure on air quality should be investigated. In other words, the relative impact of various degrees of performance on emissions should be evaluated for each measure. Measures that have a greater impact on air quality should be given more weight in a pricing framework.

In summary, the effect of driving characteristics, vehicle characteristics, and mileage would be used to determine the approximate vehicle emissions, which would then be associated with a cost based on expected externalities. Elasticities can also be used to adjust prices to bring about a desired change in behavior or overall air quality. All of these pricing components will contribute to developing a basic pricing framework, which could then be used by planners to determine an actual user fee based on the characteristics and needs of their area of oversight.

1.4.5: Task 5—Collect Data and Perform a Case Study Using the Measurement Framework

A selected highway corridor or geographic area in Texas will be used to conduct a case study using the developed user fee methodology. The selected corridor or area should represent an area where transportation has a significant air quality impact. Through a real-world application potential problems may be identified, as well as the perceived benefits and impacts of the methodology. Additionally, individual GPS runs may be used to represent theoretical drivers within the area covered by the user-fee system. By applying the developed fee methodology to real-world data, the effectiveness of the methodology can be better evaluated, and potential problems identified. Thus, recommendations for future use can be made.

1.4.6: Task 6—Summary and Conclusions

A summary will be given of the developed methodology and the results of the case study. Based on the findings of this research, recommendations for the use of performance measurement and MBUFs to address air quality problems will be made.

1.5: Research Benefits

Mileage-based user fees are currently receiving a great deal of attention across the nation as a potential way to generate transportation revenue as well as address goals such as congestion reduction. MBUFs may also be beneficial to society as a whole to the extent that they address transportation externalities and social equity. In addition, air quality and climate change are both major concerns within transportation. As the goal of this research is to incorporate the goal of emission reduction into a MBUF structure, it represents one of the first steps towards addressing additional policy goals through a mileage-based user fee system. The developed methodology for determining a pricing scheme could provide a basis for similar systems in the real world. The research also provides a compilation of various externality costs identified in literature. Finally, in addition to potential applications of such a system, this research may lead to additional investigation into the uses of MBUFs or identification of future potential research areas.

1.6: Thesis Overview

This thesis is divided into eight sections. Section 1 provides a brief introduction to the research. Section 2 presents a literature review that covers the relationship between air quality and transportation, the concept of performance measurement, and various aspects and methods of road pricing. Section 3 presents the process of identifying goals, objectives, and performance measures that relate to the reduction of vehicular emissions. Section 4 further defines the selected performance measures and discusses quantification methods. Section 5 illustrates how performance measure results can be combined into a final index to represent overall performance for an individual driver. Section 6 discusses how the final performance index may be applied for use in a mileage-based pricing scheme. Section 7 provides a real-world example of an application of the selected performance measures and pricing scheme. Section 8 presents conclusions and recommendations.

2. LITERATURE REVIEW

2.1: Road Transportation and Emissions

The development of a framework for incorporating air quality into MBUF pricing systems requires an examination of how the transportation sector impacts air quality. This allows for the identification of factors that influence emissions which may be efficiently priced to achieve desired objectives.

2.1.1: Background on Air Quality and Emissions

Air quality has become an important consideration both nationally and worldwide. Air quality consideration is no longer limited to the six criteria pollutants covered by the National Ambient Air Quality Standards; air toxics and greenhouse gases are cause for concern as well (*1*).

The transportation sector deserves significant consideration when enacting policies aimed at addressing air quality, as transportation (both on- and off-road) contributes to an estimated 50 to 60 percent of air pollution in the United States (*3*). The emission of carbon dioxide (CO_2), a greenhouse gas, increases proportionally with transportation usage. Emissions are considered a negative externality of transportation, in that the cost associated with poor air quality is borne by society as a whole, rather than just the users of the transportation system (*3*). The effects of emissions can be far-reaching or experienced near the source. At a local level, negative effects on health are troublesome. In fact, it is believed that as many as six out of ten Americans reside in areas with unhealthy levels of air pollution (*2*). At a regional scale, acidification and photochemical oxidants are a concern, while possible greenhouse effects (direct and indirect) and stratospheric ozone depletion are a global-level concern (*4*).

2.1.2: Significance of Transportation – Mobile Source Emissions

The criteria pollutants addressed by the EPA include carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and particulate matter, which can include both “fine” particles with diameters less than or equal to 2.5 micrometers ($PM_{2.5}$) and particles with diameters less than or equal to 10 micrometers and greater than 2.5 (PM_{10}) (*5*). However, rather than being directly emitted, ozone is typically formed from a chemical reaction of nitrogen oxides (NOx), volatile organic compounds (VOCs), and sunlight. In fact, the pollutants of greatest concern for the State of Texas are currently NOx, VOCs, and ground level ozone (*6*).

Aside from their relationship with ozone, volatile organic compounds are also a problem on their own merit. VOCs are the gaseous form of hydrocarbons (HC), and are common ground-water contaminants (*7*). VOCs are also a problem in the transportation field because they are often a component of petroleum fuels, and are emitted both through incomplete gasoline combustion and as a byproduct of the petrochemical industry (*8*).

Other problematic emissions include chlorofluorocarbons (CFCs), which result primarily from vehicle air conditioning within transportation, and other mobile source air toxics (MSATs). Air toxics are pollutants that are either known or expected to cause serious health problems, including cancer, birth defects, lung damage, immune system damage, and nerve damage (*9*). Currently, there are 93 compounds documented in the EPA IRIS database, including the known carcinogen benzene, and potential carcinogens 1,3-butadiene, formaldehyde, acrolein, acetaldehyde, and diesel particulate matter (*10*, *11*). VOCs are also considered MSATs. Emissions of MSATs can be reduced through emission reductions of VOC, PM, and diesel emissions (*9*).

All of these pollutants pose a serious risk to both the environment and public health. People that live very near to a highway, railroad, or airport are especially at risk, because concentrations of hazardous air pollutants increase significantly the closer one gets to these sources, and they would be exposed very often (*9*).

Of increasing importance is consideration of greenhouse gases (GHGs), which are atmospheric gases that absorb and emit infrared radiation—the basic cause of the greenhouse effect. The most abundant GHGs in Earth’s atmosphere include water vapor, carbon dioxide, atmospheric methane, nitrous oxide, ozone, and chlorofluorocarbons. The transportation sector accounts for approximately one third of all U.S. GHG emissions, and has accounted for almost half of the net increase since 1990 (*12*). Based on data from 1990 to 2006, CO_2 was the primary greenhouse gas emitted by human activities in the United States, which accounted for approximately 85 percent of total GHG emissions (*13*). Within transportation, about 66 percent results from gasoline combustion, 16 percent from diesel, and 15 percent from jet fuel (*2*).

2.1.3: Current Air Quality Legislation and Transportation Conformity

The first federal legislation involving pollution was the Air Pollution Control Act of 1955. However, air pollution control was not included until the Clean Air Act of 1963. The most recent revisions to the Clean Air Act took place in 1990 (*14*). Under the Clean Air Act, the EPA sets primary air quality standards to protect public health, and secondary standards to protect public welfare from adverse effects (including effects on vegetation, soil, plants, water, wildlife, buildings/national monuments, visibility, etc.) (*15*). As stated previously, the EPA currently has national ambient air quality standards for six criteria pollutants:

- Carbon monoxide (CO);
- Lead;
- Nitrogen dioxide (NO_2);
- Particulate matter (PM);
- Ozone; and
- Sulfur dioxide (SO_2) (*16*).

These six pollutants are referred to as ‘criteria’ pollutants because the EPA uses human health-based and/or environmentally based criteria to establish acceptable pollutant levels (*17*). They may also be damaging to property. The EPA must review the latest scientific information and standards every five years, and make changes as needed (*18*). Currently, particulate matter and ozone are considered the greatest health threats out of these six. Under the Clean Air Act, states must develop a State Implementation Plan (SIP) if any area within the state is classified as ‘nonattainment’—that is, the area has air pollution levels that “persistently exceed” the NAAQS. A SIP explains how the state will comply with and meet the NAAQS (*19*).

2.1.4: Vehicle Emission Estimation

In order to quantify emissions, appropriate sources of data must be obtained. Emission data is necessary for the development of performance measures. Actual field emission data can be obtained through use of a portable emissions measurement system (PEMS). By sampling undiluted exhaust, a PEMS unit can measure concentrations of HC, CO, CO_2, NO, O_2, and PM smaller than 1-2.5 microns, and can calculate NOx from the NO emissions (*20*).

As an alternative to directly measuring emissions, emissions data may be produced through computer modeling and simulation. Discrepancies may arise between results obtained through modeling and directly measuring emissions, with modeling accuracy dependent on assumptions made. For example, measurement of CO_2 typically involves vehicle mileage and speed figures, as well as assumptions regarding average fleet fuel efficiency (*21*). Passenger vehicles and heavy vehicles should be considered separately if possible. Different vehicle types have different emission rates, and may travel at different average speeds based on typical driver behavior (*22*). Speed is an important factor, as the emission rate for a specific vehicle will vary at different speeds. In addition, on-road travel is not the only generator of mobile-source emissions. For example, emissions are produced while a vehicle idles. In fact, research suggests that idling for a prolonged period of time produces more emissions and fuel consumption than shutdown and restart of a vehicle (*23*).

Modern technology can provide significant information about vehicular travel. Intelligent transportation systems (ITS) can provide information on vehicle volumes and turning movements. Automatic vehicle identification can provide fairly disaggregated VMT and speed data, as it tracks individual vehicles over time, potentially through the use of a global positioning system (GPS).

The EPA has created software to model mobile source emissions. The MOBILE emission modeling software, first developed by the EPA in 1978, is used frequently to estimate grams per mile current and future emissions of HC/VOC, CO, NOx, PM, and SO_2 based on average speed at a national and local level (*24*). The model accounts for changes over time, such as changing vehicle emission standards, vehicle populations, and vehicle activity. The model can also be calibrated to reflect local conditions, with variables such as temperature, humidity, and fuel quality (*25*). MOVES2010 (MOtor Vehicle Emission Simulator), which is a replacement of MOBILE6.2, has recently become available on the EPA website. This new system, developed by the Office of Transportation and Air Quality (OTAQ), can estimate emissions for both on-road and non-road mobile sources, covers additional pollutants, and allows multiple scale analysis, from the national-level down to the project-level (*26*). In addition to pollutants modeled by previous systems, MOVES2010 estimates several mobile source air toxics (MSATs). There are also some changes to the modeling approach used to estimate mobile source emissions, based on recommendations from the National Academy of Sciences (*27*). The base of emission calculation used is Vehicle Specific Power (VSP), which depends on a vehicle's instantaneous speed and acceleration, road grade, and vehicle characteristics such as weight, rolling resistance, and aerodynamic drag (*28*).

For the purpose of this research, MOVES2010 will be used to model emission rates of vehicles based on multiple characteristics, including different model years, vehicle classes, and speed profiles. In this way, relationships will be established connecting performance on different measures with expected increases or decreases in vehicle emission rates. Such performance measures include vehicle characteristics such as age and driving behaviors such as hard acceleration/deceleration.

2.2: Performance Measurement and Transportation Air Quality

Performance measurement is described by the U.S. General Accounting Office as "the ongoing monitoring and reporting of program accomplishments, particularly progress toward pre-established goals" which may address processes, outputs, or outcomes (*29*).

Performance objectives should be established based on an agency's (or program's) mission and goals. Performance measures can then be selected to aid in achievement of an objective. Robust performance measures are typically numerically based to provide context and scale. Targets can be established to quantify how good (or bad) the performance actually was.

2.2.1: Background on Performance Measurement

Many factors must be considered before implementing a performance measurement program. What is to be measured typically depends on who the users are (managers vs. external stakeholders, etc.). In addition, performance measurement is usually intended to obtain objectives in the future rather than to evaluate past actions. Unfortunately, data collected is usually associated with past events; or, at best, with current events. It is certainly difficult to directly connect future results to current results, and especially to past results (*30*). Therefore, some extrapolation must take place (*31*).

Different types of performance measures exist, but output and outcome measures are primarily used. Outcome measures are usually desirable, as they actually provide an indication of whether desired outcomes were achieved (often something the agency wants to either maximize or minimize). Output measures typically provide information on an individual activity related to the achievement of a desired outcome. In other words, outputs are what the program or agency actually did, while outcomes are the consequences of what was done (*32*). Output measures are usually much easier to define and track, however, and are more often under direct agency control (*1*).

Kaufman recommends that measures should relate to ends instead of means, processes, or resources (*33*). He identifies four scales of measurement as:

- Nominal—naming;
- Ordinal—rank ordering;
- Interval—equal scale distances with arbitrary zero-point; and
- Ratio—equal scale distances with known zero-point.

To better assure accuracy and reliability, Kaufman suggests that measures and associated objectives be measurable on an interval or ratio scale. The given reason is that objectives are measurable on these scales, while the nominal and ordinal scales are typically used for goals, aims, and purposes.

2.2.2: Characteristics of Robust and Useful Performance Measures

A 'good' performance measure requires a careful development process, which would give consideration to various desirable characteristics. Abstract measures are not very useful—rather, in order to extract any useful information, a decision-maker must understand both context and scale (*34*). The necessary data related to the measure should be realistic and reasonably attainable, and allow for regular measurement of performance to determine if any changes are needed in approach (*35*). Table 2.1 lists and describes desirable characteristics of performance measures found in literature (*1*, *32*, *36*, *37*).

Table 2.1: Characteristics Related to 'Good' Performance Measures

Attribute	Description
Measurability (Realistic)	• Are required data, analysis methods, tools, and resources available? • Can the necessary level of accuracy be achieved for the measure to be usable? • How reliable are the data sources? • Would it be feasible to take field measurements either for performance monitoring or model calibration?
Simplicity/ Clarity	• Can the measure be understood by the public, elected and appointed officials and policy makers, agency staff, and other transportation professionals?
Usefulness	• Is this measure actually useful to any stakeholders? • Does it directly measure the desired issue?
Objectivity/ Validity	• Are the measures factually based, so that the values themselves are not debatable?
Controllability	• Can the measured characteristic actually be controlled, corrected, or otherwise influenced by the agency measuring it? • Does the agency have direct or indirect control, and is that control full or partial?
Relevance	• "Is the measure relevant to planning/budgeting processes? • Does the reporting of these measures happen often enough to give decision makers the information they need as often as they need it?" (*37*)
Consistency	• Is the measure reliable? • Is there sufficient consistency between measurement methods that current and past results can be compared?
Uniqueness	• Does the measure duplicate or overlap with another?
Ability to Forecast	• Do related forecasting methods currently exist, and, if so, are they easy to use? • Would projections of this measure into future scenarios be relatively realistic? Would it allow for future comparisons of projects or strategies?
Multimodality	• Are relevant and/or desired travel modes addressed by the measure?
Ability to Diagnose Problems	• Can this measure directly diagnose problems and their causes, or does it only indicate condition such that further study or action is necessary? • Is the measure aggregated so much that a 'black box' condition might occur? • "Is there a logical link between this measure and what actions/phenomena affect it?" (*37*)
Cost Effectiveness	• Is the cost of collecting and analyzing necessary data within budget and resource limitations?
Number	• Is the number of measures presented small enough for easy communication with stakeholders? • Conversely, are all goals addressed? A hierarchical structure could be used for more detailed analysis.
Addresses Desired Temporal Scale	• Can the measure be compared over or across time? • Can the measure discriminate between performance during peak and off-peak periods, as well as different daily conditions? • "Does the measure fit well with the time frame of analysis and action?" (*37*) Is the measure intended for long-range planning, or to assess short-term impacts of decisions?
Addresses Desired Geographical Scale	• Is the measure specifically useful at a regional, subarea, or corridor level; or can it be applied to all areas of the state, region, and/or local area? • Can the measure differentiate between freeways and other surface facilities?

However, selected measures should not just exemplify the above characteristics. Measures must also be consistent with the actual needs of the agency creating them, and be specifically suited to agency goals and actions (*36*).

2.2.3: Data Requirements

The data requirement is a very important consideration when selecting performance measures. Employees have limited time, and there may be a high cost associated with data collection, storage, and retrieval (*38*). Therefore, data that is already available to the agency is desirable. However, consideration should be given to data that may be more difficult or expensive to attain, but would be more useful or valuable to decision-makers. Additionally, the frequency of data collection and reporting should depend, at least in part, on the timing needs of decision-makers.

2.3: Road Pricing

Future funding for transportation has come to be a major concern, especially considering increasing demand, aging of existing facilities, and rising construction costs (significantly due to inflation). Currently, transportation-related activities are primarily funded through sources such as the fuel tax, which is a variable cost, and state registration fees, which are fixed operating costs for the user (*39*). Additional funding sources include sales and property taxes, which are paid whether a person uses the road system or not (*40*). The federal fuel tax has not changed from 18.4 cents per gallon since 1993, and the Texas state fuel tax has remained at 20 cents per gallon since 1991 (*41*). The federal tax is eventually redistributed to states as federal aid, although not exactly what a particular state contributed due to the use of allocation formulas (Texas typically receives less than it pays in, but must receive at least 91 percent). Portions of the fuel tax are also devoted to non-road uses, such as public education. The fuel tax could be considered a distance-based user fee, although it is far from optimal, as many factors that affect vehicle-related external costs are not reflected (*42*). The cost of this fee typically increases with more miles driven—but this relationship has been degrading. For example, in Oregon fuel tax revenue (in cents per mile traveled) declined by half between 1970 and 2003, even without the effects of inflation (*43*). For the most part, the fuel tax is paid by road users, but not all users pay equally. Certainly not all users pay in proportion to the costs they inflict on the system, especially given differences between vehicle fuel efficiencies. For example, as more people begin to use technology such as electric or hybrid vehicles, fewer people will be paying for use of transportation infrastructure, and those that do will be paying disproportionately.

2.3.1: Mileage-Based User Fees

Transportation-related agencies not only need a method to adequately fund transportation in the future, but also a way to more accurately charge road users in accordance with their actual use of facilities. Various methods used to achieve such a result are termed 'road pricing'. Road pricing may include facility-based programs like a toll road or high-occupancy toll (HOT) lane, area-based programs like cordon charges, and network-wide programs like distance-based charges (*44*).

One road pricing method that can potentially address these goals is a mileage-based user fee (MBUF). In its simplest form, a MBUF system would charge users a fixed fee based the number of miles their vehicle is driven within a certain jurisdictional area (*41*). DeCorla-Souza suggests that mileage-based fees are just as beneficial as facility-based pricing (tolling), but would likely be more acceptable to the public, unlike the tolling of previously free facilities (*45*). The argument is that mileage-based fees would not be a new charge to users if they were to replace other fees like the fuel tax. Additionally, MBUFs actually allow users more opportunity to save money by reducing travel, especially if the fee incorporated currently fixed costs such as vehicle registration. Fixed costs do not change with regards to distance traveled, and about 23 percent of the user cost is fixed (*46*). It may be easier for drivers to forgo low-value travel because the cost of each mile is a direct charge to them, while current user fees are more difficult to relate to amount of travel. According to Litman, a MBUF system would be more marginal, by incorporating actual user costs imposed on the system (*42*). MBUFs can be varied to attempt to address specific policy goals such as reducing vehicle miles traveled (VMT), optimizing capacity, or reducing emissions. Some of these goals may be complementary.

MBUFs can also be used to address externalities, which are imposed on society by drivers, but are not directly paid for by drivers. In other words, the costs associated with an externality are borne by society as a whole, including people who did not directly benefit from the travel. Internal costs include fuel cost, vehicle maintenance, insurance, registration, and vehicle purchase (*47*). Typical external costs include congestion delays, road construction, environmental impacts, and social inequity. Costs may also be variable or fixed, where variable costs change with the amount driven and fixed costs do not. External costs could potentially be addressed through mileage-based user fees, including environmental impacts such as air pollution. By internalizing these costs, users may make better decisions about their travel.

2.3.2: Basic System Components

According to Whitty and Svadlenak, there are six basic things that a MBUF system must be capable of (at a minimum):

- Calculate the miles driven;
- Have access to this mileage data;
- Apply mileage-based fees to this mileage;
- Provide billing to the user;
- Collect payment; and
- Enforce payment (*48*).

Each of these components involves some form of technology. By far, the simplest approach to collecting data would be through periodically performing checks of a vehicle's odometer ('odometer audit'), which could occur when a vehicle's license and insurance are renewed, or during a scheduled vehicle servicing. This method certainly would be the simplest, and most likely the cheapest to implement since vehicles already have odometers, while many do not have any sort of GPS system. On the other hand, only a very simple and basic fee could be applied, although vehicle class could potentially be accounted for. Additionally, there would be no way of proving that some of the miles occurred in a different jurisdiction without some form of technology.

Other methods of collecting travel data include an on-board units (OBUs) or use of a GPS to track travel (*45*). Such technology allows for collection of data such as second-by-second speed. GPS units also allow for tracking of vehicle location.

2.3.3: Mileage-Based Fee Outcomes

In general, one would expect mileage fees to reduce VMT. According to Komanoff, based on what economists term the 'Law of Demand', a tax on vehicle miles traveled will result in an overall reduction of vehicle miles traveled (*49*). Thus, based simply on what we can learn from a demand curve, as the price increases, some users are no longer willing to pay that price to travel, and demand drops (VMT is decreased). However, Komanoff points out that real-world situations are typically more complex than models would suggest, especially in the field of transportation (*49*). Therefore, traveler response to MBUFs cannot be perfectly predicted with demand models.

Vehicle emissions are closely tied with the number of miles driven. Thus, if fewer miles are driven, emissions should decrease, and MBUFs encourage drivers to reduce their mileage for economic savings. Higher rates for higher emitting vehicles may also encourage the purchase of more fuel-efficient vehicles; although if the fee difference is very slight it may not be worth the cost of the vehicle to switch.

2.3.4: Examples of MBUFs

In order to determine what a good base MBUF rate would be, an investigation of various charges used in the real world or suggested in literature was undertaken. The ideal goal of the MBUF would be to induce a change in driver behavior, and thereby reduce emissions. As a MBUF would likely be a replacement of the current fuel tax, the average amount per mile paid currently with fuel purchases could be a good starting point for determining what to charge per mile. If the Texas state fuel tax of twenty cents per gallon were translated into a mileage-based amount, the fee would be approximately 1 cent per mile (*50*).

In addition, air pollutants are considered an externality of transportation. That is, they are a negative consequence that is not directly paid for by road users. Rather, the effects of air pollutants are borne by all, regardless of whether they drive or not. Thus, an additional goal of the MBUF could be to internalize some of the external environmental and health costs of emissions, so that actual road users help pay for the damage. Calculating the actual unit cost for each pollutant type, however, is difficult as the relationship between emissions and resulting damages is not concrete. A general idea of the cost of emissions is illustrated in Table 2.2 (*51*). The values were derived by the National Highway Traffic Safety Administration (NHTSA) based on EPA estimates.

Table 2.2: NHTSA Estimated Damage Costs of Emissions (*51)*

Pollutant	**Damage Cost (in 2007 ¢)**
VOC	¢0.1874/gram
NOx	¢0.4409/gram
PM	¢18.5188/gram
SO_2	¢1.7637/gram
CO_2 (U.S. domestic value)	¢0.0002/gram
CO_2 (mean global value)	¢0.0033/gram

These values could be used to obtain a mileage-based cost for each pollutant, if the vehicle's emission rates are known, calculated as (Equation 2.1):

$$vehicle's\ cost\ in\ {}^{¢}/_{mile}\ for\ each\ pollutant = \left(total\ pollutant\ damage\ cost\ in\ {}^{¢}/_{g}\right) \times \left(vehicle's\ {}^{g}/_{mile}\ of\ pollutant\right) \qquad 2.1$$

To complete this example of using emission externality cost to determine a mileage-based fee, the cost of each pollutant for a 2010 or newer vehicle in each vehicle category was calculated using base emission rates obtained from the EPA MOVES2010 program. Table 2.3 shows the results.

Table 2.3: Example Mileage Fees from Emissions Damage Costs

Vehicle Type	Damage Cost Per Pollutant in ¢/mile					Total ¢/mile
	CO_2	VOC	NOx	CO	$PM_{2.5}$	
Passenger Car	0.095	0.0007	0.0151	0.0000	0.0403	**0.151**
Passenger Truck	0.117	0.0045	0.0799	0.0000	0.0485	**0.250**
Motorcycle	0.075	0.1570	0.1842	0.0000	0.2930	**0.709**
Single-Unit Truck	0.457	0.0100	0.5154	0.0000	0.5578	**1.540**
Bus	0.308	0.0099	0.3410	0.0000	0.2640	**0.923**
Combination Truck	0.530	0.0101	0.5653	0.0000	0.5761	**1.681**

An example of a mileage-based pricing system in the real world is the German Lkw-Maut system, which charges both domestic and foreign freight vehicles greater than 12 tons for use of certain roads (*52*). The purpose is to internalize the wear and tear that heavy-duty vehicles impose on roadways, thus providing funding for maintenance. This system does include emissions consideration to an extent. The amount charged per kilometer depends on the aspects of the vehicle—the number of axles and the emissions class. In addition, certain particle reduction retrofits allow trucks to be charged at a lower level.

Another example of real-world mileage-based pricing is pay-as-you-drive (PAYD) insurance. With PAYD insurance, a pricing incentive is given to drivers to decrease their mileage, thereby decreasing their risk of a crash. A 1 percent decrease in mileage roughly corresponds to a 1.7 percent reduction in crash costs (*53*). Encouraging fewer miles driven is thus beneficial to insurance companies by reducing insurance claims. A 2006 pilot program conducted by Progressive Insurance in Texas resulted in drivers decreasing their mileage by about 10 percent (*54*). Additionally, PAYD insurance includes the possibility of pricing to influence other driver behavior. Progressive Insurance offers discounts up to 30 percent for good driving behavior, which they determine through a logging device used by a driver for a month (*55*). Algorithms used to determine pricing are trade secrets of these companies, but the idea is useful for mileage pricing in this research.

Other distance-based charging schemes include recent pilot programs conducted by the Minnesota DOT (MnDOT) and the Oregon DOT (ODOT). An overview of various distance-based charges is shown below in Table 2.4.

Table 2.4: Overview of Various Tolls Either Suggested by Literature or Used in Real-World Applications

Toll/Rate	Location or Source	Description
7¢/mile	Literature (*46*)	Approximate rate per mile from an average insurance premium of $850 per vehicle-year
2¢/mile	Literature (*46*)	Approximate rate per mile from average registration and licensing fees of $250 annually
5-25¢/mile	MnDOT (5*6)*	Amount used in Minnesota DOT pilot project to determine driving behavior based on different PAYD insurance rates
1.5¢/mile	Literature (*57*)	External local pollution cost
20¢/mile	Literature (*54*)	Approximate mileage cost of fuel at $4 per gallon
0.141-0.288 €/km (29.0 - 59.2¢/mile)	Germany (*58*)	German fee system for heavy-duty trucks, based on emissions class and number of axles; internalizes cost of infrastructure provision and operation attributed to heavy-duty vehicles
1.2¢/mile	ODOT (*59*)	Replacement of 24-cent-per-gallon gas tax assuming 2004 average of 20 mpg; for Oregon user fee pilot program
2, 10, & 20 p/km (4.8, 25.8, & 51.5¢ /mile)	Leeds, UK (*60*)	Mileage rates examined for air quality responses within a cordon zone for Leeds, UK
0.6-3.3¢/mile	Literature (*61*)	Mileage rates to replace fuel tax based on average fuel efficiency of 18 vehicle classes
7¢Can/km (11.23¢/mile)	Literature (*62*)	Average PAYD insurance rate based on average vehicle insurance premiums and average mileage; estimated to reduce affected vehicles' average annual mileage by 10-15 percent

The above table gives a variety of road charges, and provides some idea of the range of prices that may be charged to the user.

For this research, the primary goal with pricing is to influence driver behavior to an extent that emissions are lowered. Of particular interest is the Minnesota PAYD pilot project, which utilized a range of mileage rates to determine driver response, with observations of 100 drivers and 30 drivers in a control group (*56*). The drivers were charged between 5 and 25 cents per mile, with rates randomly assigned to participants and some rates varying for peak and off-peak travel. The final report for the project included data for each individual driver (*63*). These data were analyzed, and results are shown in Figure 2.1.

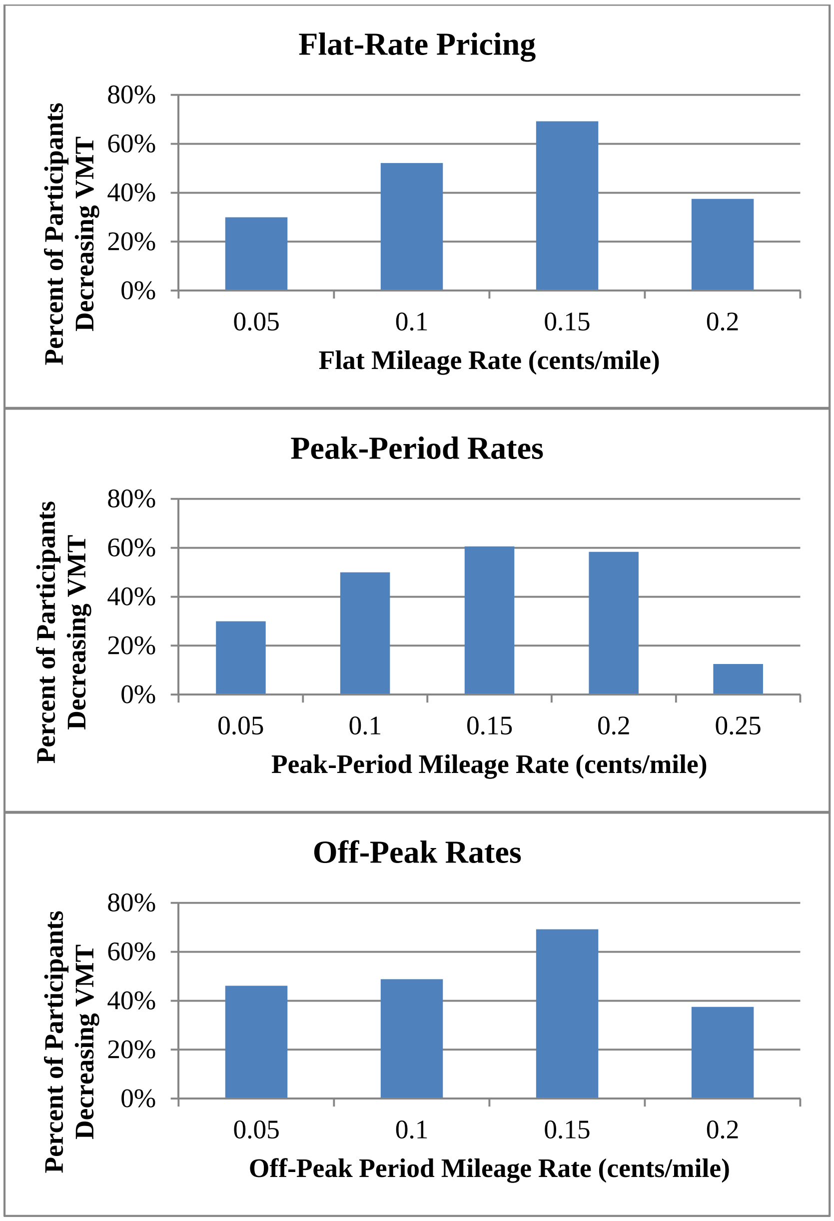

Figure 2.1: Percent of participants that decreased mileage from the Minnesota PAYD experiment results.

The above graphs show that the largest percentage of participants that decreased their mileage occurred for participants priced at 15 cents per mile.

2.3.5: Elasticity in Transportation

Changes in the cost of travel affect the demand for travel. When the cost increases, the 'consumption' of travel decreases—that is, less travel occurs. Elasticity is used to determine how sensitive consumption is to changes in price. Elasticity is typically defined as the percent change in consumption related to a 1 percent change in price. For example, if the elasticity of mileage with respect to the gas tax is -0.3, then a 1 percent increase in the gas tax will result in a 0.3 percent decrease in mileage. If the absolute value of the elasticity is less than one, the relationship is termed 'inelastic,' meaning that consumption changes at a lower rate than price. The closer the elasticity is to zero, the less influence price changes have on consumption. Transportation is generally considered to be inelastic. However, even with relatively low elasticities, pricing measures can have an impact on travel behavior (*64*).

In transportation, arc elasticity is most frequently used (*65*). Arc elasticity is calculated as (Equation 2.2):

$$Elasticity\ (\eta) = \frac{\log(Q_2) - \log(Q_1)}{\log(P_2) - \log(P_1)} \qquad 2.2$$

The demand before and after is represented by Q_1 and Q_2, respectively. Similarly, the initial and final prices are represented by P_1 and P_2. If the elasticity value is known, the demand resulting from a price change could be determined as (Equation 2.3):

$$New\ Demand\ (Q_2) = Q_1 \times ({}^{P_2}/_{P_1})^{\eta} \qquad 2.3$$

Similarly, if a certain change in demand were desired, the new price required to cause the change could be calculated as (Equation 2.4):

$$New\ Price\ (P_2) = P_1 \times ({}^{Q_2}/_{Q_1})^{1/\eta} \qquad 2.4$$

However, the above equations are not applicable if any of the demand or price values are zero.

There are many estimated values of transportation elasticities in literature. For example, Table 2.5 shows ranges associated with different types of price changes compiled from various studies (*65*).

Table 2.5: Example Ranges of Estimated Elasticity Values

Estimated Component	Fuel Price	Income	Taxation (Other than Fuel)	Population Density
Car Stock (vehicle ownership)	-0.20 to 0.0	0.75 to 1.25	-0.08 to -0.04	-0.7 to -0.2
Mean Fuel Intensity (fuel efficiency)	-0.45 to -0.35	-0.6 to 0.0	-0.12 to -0.10	-0.3 to -0.1
Mean Driving Distance (per car per year)	-0.35 to -0.05	-0.1 to 0.35	0.04 to 0.12	-0.75 to 0.0
Car Fuel Demand	-1.0 to -0.40	0.05 to 1.6	-0.16 to -0.02	-1.75 to -0.3
Car Travel Demand	-0.55 to -0.05	0.65 to 1.25	-0.04 to 0.08	-1.45 to -0.2

The above table gives an average elasticity value of -0.2 relating yearly driving distance to changes in fuel price. As the amount spent on fuel increases proportionally to increases to mileage driven, we can assume that drivers behave similarly with regards to mileage fees, which are proportional to mileage as well.

2.4: Concluding Remarks

Air quality is presently a major concern, from criteria pollutants to air toxics and greenhouse gases. Air pollution negatively impacts both human health and the environment. A significant portion of pollutant emissions can be attributed to the transportation sector as a whole, although for this research the focus is on-road transportation. Emissions are directly related to the amount of driving. However, many other factors, such as vehicle types and driving behaviors, affect the amount of emissions as well. Performance measurement can be used to relate transportation to resulting emissions. Measures are typically selected to meet desired goals. In this case, performance measurement will be used to address air quality goals. In order to induce better performance, and thus attempt to meet goals, a road pricing system will be used. Many different methods of road pricing were identified, including congestion tolling, weight-based fees, and distance-based fees. Mileage-based user fees will be further explored in this research, as such a system will give a financial incentive to reduce driving, which will in turn improve air quality overall. Thus, in this research pricing is used to achieve air quality goals rather than improving congestion or generating revenue, as is often done. Finally, existing real-world pricing provides a good starting point for establishing a MBUF. Based on work done by the Minnesota DOT, increasing the mileage fee from 10 to 15 cents per mile resulted in the greatest change in driver behavior.

The next section outlines the process of selecting appropriate goals, objectives, and performance measures. The literature review forms an important basis for identification of applicable measures, both through identification of actual measures suggested in literature and of air quality concerns that could be addressed through performance measurement. In addition, the literature review contributes significantly to the process of establishing a user-fee system in later sections.

3. DEVELOPING A FRAMEWORK OF PERFORMANCE MEASURES

3.1: Approach

The goal of this research was to examine how it would be possible to address air quality concerns with road pricing. Performance measurement is used to achieve set goals by identifying certain areas for improvement and quantifying how various levels of improvement relate to goal attainment. For this research, performance measures that link transport to pollutant emissions and fuel consumption are selected. Improved performance leads to higher achievement of goals, so a financial incentive for better performance would help to achieve goals. Therefore, performance measurement is used to influence mileage-based pricing in the hopes of encouraging travel that will improve air quality.

3.1.1: Research Scope

Applicable measures are those related directly to roadway vehicles and operation. Thus, off-road vehicles and equipment, such as recreational vehicles, farm equipment, and construction equipment, do not fall under the research scope as they are unlikely to fall within the purview of an MBUF system. Transit-related measures were considered applicable, but other modes such as air travel and ferries were not considered. The six categories of vehicles selected for consideration are based on vehicle categories used in the EPA's MOVES program, as shown in Table 3.1.

Table 3.1: Potential Mobile Categories Used for This Research

Category	Type	Description
Light-Duty Vehicles	Passenger Cars	Passenger cars
	Passenger Trucks	Includes pickup trucks, minivans, passenger vans, and sport utility vehicles (SUVs); Light light-duty trucks have a Gross Vehicle Weight Rating (GVWR) of less than 6,000 lb, while heavy light-duty trucks go up to 8,500 lb
	Motorcycles	Design for on-road use, 2 or 3 wheels
Heavy-Duty Vehicles	Single-Unit Trucks (Medium-Duty)	Includes refuse trucks, short-haul single unit, long-haul single unit, and motor homes, or recreational vehicles
	Buses	Includes intercity buses, transit buses, and school buses
	Combination Trucks	Includes short-haul and long-haul combination trucks

However, the analysis discussed in later sections applies only to light-duty vehicles, as necessary data were not readily available for heavy-duty vehicles. Due primarily to data considerations, light-duty vehicles were eventually selected as the focus of this research, although much of the developed methodology could be applied to heavy-duty vehicles if desired.

3.1.2: Assumptions

There were many assumptions that contributed to the direction taken with goals, objectives, and measures. One of the primary assumptions within this research is that the entire focus is on air quality goals. In other words, while there are many other important considerations involved in transportation policy such as accessibility, safety, and mobility, and considerations within pricing such as equity and revenue, such important factors were not considered in this case.

Another very important assumption is that the necessary technology would be available to implement the developed system. This assumption is extremely important in selection of measures, as many potential measures are technology-dependent. For example, many potential measures would require GPS technology to obtain relevant data. Such data could include location, time, and second-by-second speed data. In addition, it was assumed that every driver has access to the necessary technology. In a real-world situation, this is likely to not be the case, as the cost of such technology may be prohibitive to some segments of the population and there is likely to be a significant percentage of non-adopters.

3.1.3: Development of Overall Goals and Objectives

As stated in the literature review, goals are used to identify the primary focus for the fee system. In other words, goals broadly define the desired outcomes. Objectives are then used to further define focus areas that will be addressed in order to fulfill the goals. Performance measurement is then used to identify and evaluate specific actions undertaken to achieve the desired objectives. A useful illustration of this concept is found in the draft of the *TxDOT 2011-2015 Strategic Plan*, as shown in Figure 3.1.

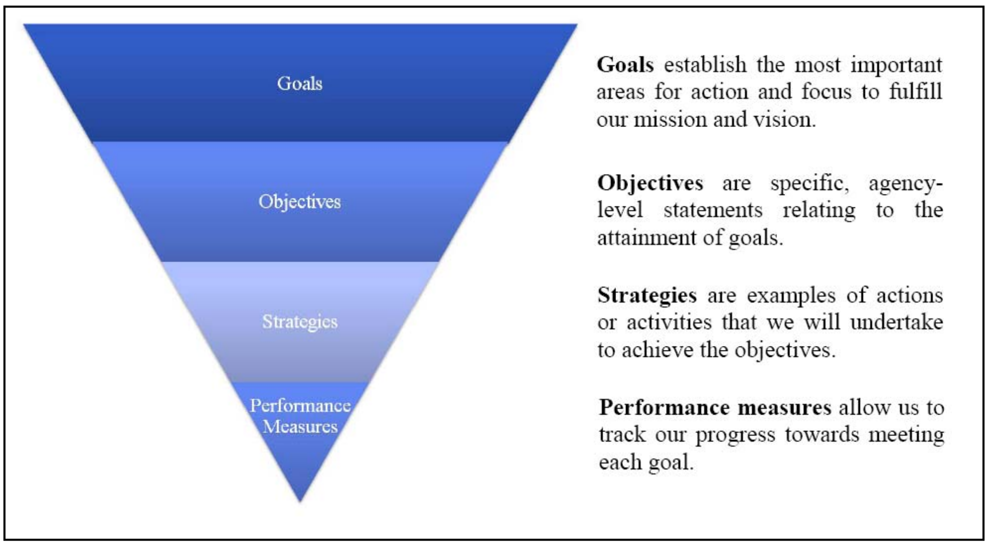

Figure 3.1: Illustration of goals, objectives, and performance measures (reprinted from *66*).

As shown, goals address a broad view of the subject, and objectives and measures are used to progressively narrow in on the many factors related to attainment of goals.

3.1.4: Identification and Selection of Goals

The primary purpose of the mileage-based user fee system developed in this research is to address air quality concerns within the system area. Thus, it is desired that the system will result in the reduction of vehicle-related emissions. A primary concern is the emission of the six 'criteria pollutants' defined by the EPA in the NAAQSs, which include ground-level ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead. Other pollutants may also be considered, such as air toxics. In addition, climate change is a growing concern across the nation, so addressing the emission of greenhouse gases such as carbon dioxide is also important. While the emission of pollutants and GHGs are often related, strategies for addressing their emission may differ. Thus, goals should include both a reduction in pollutant emissions and in GHG emissions.

In addition to reducing emissions, addressing the impacts of these emissions is important. Emissions may have an effect on both the environment and on human health, as discussed in the literature review, so it is therefore desirable to reduce these impacts. While such goals are related to the reduction of emissions, they are important considerations to keep in mind throughout the process of selecting objectives and measures as it is unlikely that a total elimination of vehicular emissions is possible. As a result, the selected goals of this research include:

1. Reduce pollutant emissions from vehicles operating in the effective user fees system area;
2. Reduce greenhouse gas emissions from vehicles operating in the effective user fees area;
3. Reduce the impact of emissions on the population residing in the effective user fees area; and
4. Reduce the impact of emissions on sensitive environmental elements in the effective user fees area.

Finally, it should be noted that Goals 3 and 4 are significantly related to Goals 1 and 2, as reduced emissions would reduce environmental and health impacts. Therefore, these goals could be considered as a subset to Goals 1 and 2.

3.1.5: Identification and Selection of Objectives

Objectives for this research were not directly identified based on the four established goals. Rather, based on the literature review, eight objectives that can be pursued to meet the goals were identified. These encompass ways to reduce actual emissions and the impact of emissions, and include objectives related to both vehicle performance and driver behavior. The selected objectives are shown below in Table 3.2.

Table 3.2: Research Objectives, Descriptions, and Relation to Goals

Objectives:		Description and Application:	Goal 1: Reduce pollutant emissions	Goal 2: Reduce GHG emissions	Goal 3: Reduce impacts on human health	Goal 4: Reduce impacts on the environment
1	Reduce the number of miles of travel in a vehicle	There is a direct relationship between mileage and emissions, so reducing total miles driven would decrease emissions of both pollutants and GHGs.	●	●	●	●
2	Reduce driving in a specific sub-area and/or at a specific time	It may be desirable to try to limit the amount of vehicles in certain areas or at certain times to decrease emissions or improve air quality. For example, congestion increases emissions, so encouraging drivers to divert to different routes or avoid rush hours may improve the situation. Other areas or times to be considered could include environmentally sensitive areas and ozone action days.	●	●	●	●
3	Increase percentage of drivers driving lower emissions vehicles	'Cleaner' vehicles that emit fewer pollutants per mile would decrease overall emissions.	●	**	●	**
4	Increase percentage of drivers driving more fuel efficient vehicles	Emission of GHGs is related to the amount of fuel used; therefore, more fuel-efficient vehicles would be expected to emit fewer GHGs per mile.	**	●	**	●
5	Increase use of public transportation	If more people use public transportation, there would be fewer vehicle-miles emitting pollutants and GHGs. Also, congestion situations may be improved.	●	●	●	●
6	Reduce driving behaviors that increase emissions	Driving behavior plays a part in both emissions and fuel consumption levels. Behaviors that affect emissions include hard acceleration ('aggressive driving'), high speeds, idling, and not maintaining the vehicle.	●	●	●*	●*
7	Increase freight efficiency and use of preferable modes	By driving with full loads, the number of freight trips may be decreased. Also, some freight modes are lower emitters than others.	●	●	●	●
8	Begin or increase participation in training for better driving behavior/eco driving	People can improve their driving behaviors to emit less and consume less fuel, but may not know how to do so. Such training would provide guidance on desired behaviors.	●	●	●	●
*when applied to a specific/applicable sub-area						
**while this objective would help to achieve the goal, the primary focus is on addressing other goals						

All of the objectives can be applied to multiple goals, meaning that all objectives can be used to address both pollutant emissions and greenhouse gas emissions. This in turn tends to reduce impacts on human health and environment. Several other objectives were suggested in brainstorming sessions, but were determined to fall within the scope of the above objectives, and can be better addressed at the performance measure level.

As shown, all of the objectives address factors that in some way affect the amount of pollutant or GHG emissions per trip or per mile. The MBUF will, therefore, be related to performance measures that help to achieve these objectives.

3.2: Development of Performance Measures

Based on the objectives identified above, performance measures were researched, discussed, and narrowed down to identify the most applicable measures to this research. For the most part, measures address very specific aspects of vehicle travel that affect emissions and over which the driver has some control.

An extensive list of potential measures for each objective was created based on the literature review. In addition to measures suggested in literary sources, the current practices of state DOTs were examined; however, many measures used by DOTs were useful for evaluating agency performance, but were not applicable to this research.

For each objective, the measures identified through literature review and brainstorming sessions are listed. Next, the process behind selection of a final measure to represent the objective is discussed. The final selected measures are further discussed in the next section.

3.2.1: Objective 1—Reduce the Number of Miles of Travel in a Vehicle

The initial set of potential measures for Objective 1 includes:

- ➢ Total VMT in the area per payment period—weekly/monthly/annually;
- Ton-miles for freight movement instead of VMT;
- Drive-alone rate (could be assessed by use of high-occupancy (HOV) lane);
- Mean or median length of trips by mode (or class of vehicles);
- Total annual VMT in the area;
- Total annual VMT per capita in the area; and

- Mode/vehicle class share for the area.

The initial lists of potential measures were further refined and narrowed through several brainstorming sessions conducted by TTI researchers specializing in air quality and pricing. Since reducing the total number of miles traveled requires the tracking of actual mileage, VMT was determined to be of primary importance for this objective. Additionally, tracking of mileage is necessary to utilize a per-mile charge. Finally, measuring freight ton-miles rather than just VMT for heavy vehicles would be desirable if heavy-duty vehicles were included in the MBUF system.

3.2.2: Objective 2—Reduce Driving in a Specific Sub-Area and/or at a Specific Time

Originally identified measures related to Objective 2 include:

- Driving within congested areas (potentially during specified times) such as on major freeways or in a Central Business District;
- Driving in locations with known endangered animal or plant species, or habitats;
- Driving near sensitive areas such as schools and hospitals;
- Driving in nonattainment areas versus attainment areas;
- Driving in areas based upon ambient air quality levels;
- Driving in areas with historically, culturally, or socially significant resources;
- Driving in hillier areas if other routes are available;
- Driving during congested times of day (and potentially only certain locations), such as during peak hours;
- Driving during Ozone Action Days;
- Driving on weekdays versus weekends; and
- Driving during summer versus winter, which could affect emissions levels based on temperature.

Through the brainstorming session, it was determined that VMT would also be an appropriate measure for this objective. However, VMT would be broken down into location and time categories. The final measure selected was

- ➢ VMT traveled in certain locations or at certain times.

Many of the above suggested measures could be potentially used as categories to classify mileage, at the discretion of the agency implementing the system.

3.2.3: Objective 3—Increase Percentage of Drivers Driving Lower Emissions Vehicles

The initial set of measures related to Objective 3 includes:

- Vehicle age;
- Vehicle weight or equivalent single axle load (ESAL);
- Vehicle class;
- Vehicle emissions rating based on EPA classification;
- Whether the vehicle is electric, hybrid, or an alternative fuel vehicle (AFV);
- Presence or installation of retrofitted technology;
- Fuel composition and/or octane level; and
- Installation of devices such as filters, etc. in trucks to lower emissions.

As demonstrated through this list, applicable measures for this objective apply directly to aspects of the vehicle itself. It was determined that the measures used for this objective would depend primarily on data availability. For example, knowing the approximate tons of pollutants emitted by an individual vehicle would be the most informative measure, but would be very difficult to measure without some major technology component. Vehicle class will be used for all system-level measures, so that individual vehicles are only compared to system measures representing the same vehicle class. Vehicle weight ties in to some extent to vehicle class, and is also much more difficult to measure than vehicle class. From further meetings, it was decided that the vehicle emission rating would be the preferable measure. Vehicle age and vehicle class would also be necessary in order to determine the emission rating for light-duty vehicles.

3.2.4: Objective 4— Increase Percentage of Drivers Driving More Fuel-Efficient Vehicles

Some of the initial measures identified for Objective 3 would also be applicable to Objective 4, while some are unique to Objective 4. This set of potential indicators includes:

- Vehicle age;
- Vehicle weight or ESALs;
- Vehicle class;
- Whether the vehicle is electric, hybrid, or AFV;
- Presence or installation of retrofitted technology;

- Engine efficiency;
- Fuel composition and/or octane level;
- ➢ Vehicle fuel-efficiency (as stated by the manufacturer or measured in-vehicle);
- Fuel usage (gallons/payment period) based on fuel type (i.e., gasoline, diesel, alternative fuel);
- Percent vehicle lights using light-emitting diode (LED) bulbs;
- Tons of GHGs emitted; and
- Vehicle size (related to wind drag), or air drag on vehicle.

Again, these measures apply to aspects of the vehicle itself, rather than driving behavior. Many of the potential measures for this objective are similar to the ones for Objective 3, as many vehicle aspects affect both fuel consumption and emission rates. Again, the most desirable measure would be the actual fuel consumed by an individual vehicle, but this would also be the most difficult to measure. Although the fuel efficiency given by the vehicle manufacturer is only an average value, it was believed to be sufficient for the purpose of this research. While actual fuel efficiency fluctuates depending on driving behaviors and speeds, these factors will be represented to some extent through other objectives. Vehicle age could be used to help determine fuel efficiency in lieu of manufacturer data.

3.2.5: Objective 5—Increase Use of Public Transportation

The initial set of measures related to Objective 5 includes:

- Transit availability;
- Passenger volume on public transportation;
- Passenger-miles on public transportation; and
- ➢ Number of trips a person takes on public transportation.

Based on the brainstorming session, the measures were narrowed down to ridership on transit, based either on number of trips or passenger miles traveled, depending on which is easier to track.

This measure would not easily tie directly into calculation of a per-mile user fee, but would most likely manifest as some sort of waiver or reduction in the final charge to the user. Thus, this measure will serve as an incentive to use transit. As transit may not be available for all users within the system, users should not be penalized for not using transit. In addition, it was discussed that measurement in this case would likely require a technology component, such as a device similar to a toll tag that would track when a person enters a transit vehicle.

3.2.6: Objective 6—Reduce Driving Behaviors That Increase Emissions

Identified measures that relate to Objective 6 include:

- Percent of time with additional power use such as air conditioning (AC), heating, radio, etc.;
- Extended idling versus auxiliary power units for trucks;
- Refueling time of day;
- Tracking whether vehicle is properly maintained (potentially using internal computer), such as brake condition, tire condition, emissions-control system, etc.;
- ➢ Frequency or occurrence of high acceleration or deceleration;
- Percent of time spent idling;
- ➢ Percent of time speed exceeds a specified amount;
- Amount of hill climbing; and
- Coasting instead of excessive hard braking.

Many different driving behaviors, as well as other behaviors like maintaining the vehicle, affect the emission rates of the vehicle.

Out of the many possible measures, vehicle speed and 'aggressive' driving behaviors were selected as the measures that would have the most influence on emission levels, and had the greatest potential to be measured. In addition, only speeds that exceed a determined 'optimal' speed would be considered, rather than including very low speeds. While very low speeds also have a negative influence on emission levels, low speeds are typically not avoidable by the driver as they tend to pertain to stops at traffic signals and congestion. Similarly, vehicle idling time was dismissed as potentially out of the driver's control. So-called aggressive driving behaviors are also targeted in that such behaviors can be avoided for the most part by the driver. Measures related to this objective would require a technology component such as a GPS system or an on-board diagnostic system.

3.2.7: Objective 7—Increase Freight Efficiency and Use of Preferable Freight Modes

Potential measures related to Objective 7 include:

- Ton-miles for freight movement instead of VMT, by mode;
- Number of empty freight trips;
- Emissions and fuel consumption per ton-mile for different freight modes; and
- Percent of freight movement by mode.

Through the brainstorming session, it was discussed that shifting freight to modes that emit fewer pollutants and consume less fuel is desirable. However, shifting of freight to other modes may not relate to individual drivers in a way that is applicable to the fee framework. Encouraging fewer empty freight trips would hopefully reduce the total number of trips taken. Additionally, ton-miles would likely be a more useful performance measure than just mileage for freight trips.

However, light-duty vehicles were eventually selected as the focus of this research, so this objective was not addressed further. Such measures could be considered in future research, especially if heavy-duty vehicle data were more readily available.

3.2.8: Objective 8—Begin or Increase Participation in Training or Web-Based Resources for Better Driving Behavior or Eco-Driving

The measures associated with Objective 8 include:

- ➢ Participation in some sort of online training to promote 'green' driving habits; and
- How often such training is completed.

The idea behind this objective was to encourage training of drivers to make them aware of eco-driving behaviors. For example, while 'aggressive' driving behaviors are addressed in Objective 6, individual drivers may not be aware of what such behaviors are.

Again, this measure would not likely tie into calculation of a per-mile fee, but would rather likely be applied as a waiver or reduction from the final user amount the driver owes for a certain billing period. Researchers discussed the fact that such a training program would need to be available before this measure could be used. Such a program might be similar to defensive driving training currently available online. In addition, it would have to be determined whether participation would apply throughout the year that it was taken or just to one billing period, and whether the training would be ‘renewed’ periodically.

3.3: Concluding Remarks

Performance measurement is used in this research to link pricing to achievement of air quality goals. The relationship among performance measures, objectives, and goals was discussed in this section. Performance measures identify very specific elements to be acted upon to address objectives, which in turn define important components of achieving goals. The overall goal of the research is to improve air quality. Thus, the defined goals represent what should be achieved through performance measurement and pricing:

1. Reduce pollutant emissions from vehicles that are operating in the effective user fees system area;
2. Reduce greenhouse gas emissions from vehicles that are operating in the effective user fees area;
3. Reduce the impact of emissions on the population residing in the effective user fee area; and
4. Reduce the impact of emissions on sensitive environmental elements in the effective user fees area.

Eight objectives were selected that relate to the above air quality goals, although Objective 7 will not be addressed in this research, as the focus of this research will be light-duty vehicles only.

In addition, many performance measures were identified that could be used to address each objective. These measures were narrowed down to a total of nine—at least one for each objective, as shown in Table 3.3.

Table 3.3: Summary of Selected Performance Measures

Objectives:		Selected Performance Measure	
1 -	Reduce the number of miles of travel in a vehicle	1 -	Vehicle-miles traveled
2 -	Reduce driving in a specific sub-area and/or at a specific time	2 -	Vehicle-miles traveled in certain locations and at certain times
3 -	Increase percentage of drivers driving lower emissions vehicles	3 -	Vehicle emissions rating
4 -	Increase percentage of drivers driving more fuel efficient vehicles	4 -	Vehicle fuel economy
3 and 4		5 -	Vehicle age
5 -	Increase use of public transportation	6 -	Trips on transit
6 -	Reduce driving behaviors that increase emissions	7 -	Time traveled at greater than optimal air quality speed
		8 -	Time spent with 'hard' accelerating/braking
7 -	Increase freight efficiency and use of preferable modes	--	N/A
8 -	Begin or increase participation in training for better driving behavior/eco driving	9 -	Driver training participation

The next section addresses details of each selected measure, including potential data requirements.

4. QUANTIFICATION OF THE PERFORMANCE MEASURES

4.1: Measure 1—Vehicle-Miles Traveled

This measure is of primary importance, since the fee to be developed is charged on a per-mile basis. Mileage also significantly affects the amount of pollutants emitted by the vehicle. The measure at the individual level would be composed of the VMT per billing period. In this case, the input would be the same as the output. The data requirement for this measure could be fulfilled simply by odometer readings, which is favored by the public for privacy reasons. However, GPS data would also be useful, especially as an extra check of the data.

4.2: Measure 2—Vehicle-Miles Traveled in Certain Locations and At Certain Times

The applicable times and locations for this measure can be changed as desired, and selected based on policy. Locations could be determined by zones or be composed of certain roadway facilities. Times could include different hours in the day, or different days such as weekdays and weekends. The tables presented in this section illustrate one example of how this measure could work. In addition, mileage could potentially be used from this measure for pricing, in that higher mileage fees could be applied in certain locations or at certain times rather than one rate being applied to overall mileage provided by Measure 1. However, the use of both Measure 1 and Measure 2 would provide quality assurance since mileage is of utmost importance.

4.2.1: Measure 2 Example

For this measure, mileage would need to be divided into categories based on when and where the mileage occurred. For this measure, a GPS system would be required so that location or time could be tracked along with mileage. Mileage could then be totaled at the end of the billing period based on time and location, as demonstrated in Table 4.1.

Table 4.1: Example of Individual Mileage by Time and Location Categories

Area (Location)	**Time**						**Area Total (miles)**
	Normal Days			**Ozone Action Days**			
	AM Peak (miles)	PM Peak (miles)	Off-Peak (miles)	AM Peak (miles)	PM Peak (miles)	Off-Peak (miles)	
A	100	100	0	20	10	0	230
B	50	50	75	20	10	15	220
C	50	50	25	10	5	10	150
Time of Day Total	200	200	100	50	25	25	**TOTAL**
	500 miles			100 miles			**600 miles**

The above table shows mileage that occurred in three separate areas and at different times, for illustration purposes only. Times were further disaggregated by separating mileage that occurred on ozone action days. Different mileage fees could be applied to the above mileage. For example, higher mileage fees could be applied to mileage that occurred during ozone action days or to mileage that occurred in desired locations, such as environmentally-sensitive areas or nonattainment areas. As stated, the above table is only an example of how data could be disaggregated for this measure.

While this measure also tracks mileage, it requires much more detailed data than Measure 1. For this measure, some sort of GPS system would be necessary in order to track both location and time of travel.

4.3: Measure 3—Vehicle Emissions Rating

The vehicle emissions rating gives an overall view of how the vehicle performs in relation to the amount of pollutant emissions. For light-duty vehicles, the emissions rating is fairly easy to determine. The EPA offers an Air Pollution Score for many different makes and models in its online Green Vehicle Guide (*67*). While older vehicles may not be found in this guide, their score could be determined based on vehicle class, as shown in Table 4.2.

Table 4.2: EPA Air Pollution Scores

US EPA Federal Air Pollutant Emission Standards for Light-Duty Vehicles								
Tier 2 Program								
Air Pollution Score	Model Year	Vehicle Types	Emission Limits at Full Useful Life (100,000 to 120,000 Miles)					
			Maximum Allowed Grams per Mile					
			NOx	NMOG	CO	PM	HCHO
10	2004+	LDV, LLDT, HLDT, MDPV	0.00	0.000	0.0	0.00	0.000
9	2004+	LDV, LLDT, HLDT, MDPV	0.02	0.010	2.1	0.01	0.004
8	2004+	LDV, LLDT, HLDT, MDPV	0.03	0.055	2.1	0.01	0.011
7	2004+	LDV, LLDT, HLDT, MDPV	0.04	0.070	2.1	0.01	0.011
6	2004+	LDV, LLDT, HLDT, MDPV	0.07	0.090	4.2	0.01	0.018
5	2004+	LDV, LLDT, HLDT, MDPV	0.10	0.090	4.2	0.01	0.018
4	2004+	LDV, LLDT, HLDT, MDPV	0.15	0.090	4.2	0.02	0.018
3	2004+	LDV, LLDT, HLDT, MDPV	0.20	0.125	4.2	0.02	0.018
3	2004-2008	HLDT, MDPV	0.20	0.156	4.2	0.02	0.018
2	2004-2006	LDV, LLDT	0.30	0.090	4.2	0.06	0.018
2	2004-2006	LDT2	0.30	0.130	4.2	0.06	0.018
2	2004-2008	HLDT, MDPV	0.30	0.180	4.2	0.06	0.018
1	2004-2006	LDV, LLDT	0.60	0.156	4.2	0.08	0.018
1	2004-2008	HLDT, MDPV	0.60	0.230	6.4	0.08	0.027
1	2004-2008	LDT4, MDPV	0.60	0.280	6.4	0.08	0.027
0	2004-2008	MDPV	0.90	0.280	7.3	0.12	0.032
Tier 1 Program								
1	1994-2003	LDV	0.60	0.310	4.2	0.10	--
1	1994-2003	LDT1	0.60	0.310	4.2	0.10	0.800
0	1994-2003	LDV	1.25	0.310	4.2	0.10	--
0	1994-2003	LDT1	1.25	0.310	4.2	0.10	0.800
0	1994-2003	LDT2	0.97	0.400	5.5	0.10	0.800
0	1994-2003	LDT3	0.98	0.460	6.4	0.10	0.800
0	1994-2003	LDT4	1.53	0.560	7.2	0.12	0.800

*note: the acronyms used in this table are defined in the Nomenclature Section

Thus, for light-duty vehicles, the score would be a fixed value for the vehicle, and could be fairly easily determined from online resources, given vehicle model and year.

For heavy-duty vehicles, the EPA does not provide such scores. A ranking system of heavy-duty vehicles based on class and year could be used if heavy-duty vehicles were investigated in the future.

4.4: Measure 4—Vehicle Fuel Economy

Actual vehicle fuel economy depends on factors such as fuel type and vehicle type. For the purpose of this measure, the fuel economy will depend on these factors. The measure for an individual vehicle will be a set value. The EPA includes fuel efficiency information for all the vehicles listed in their *Green Vehicle Guide*. Both ‘city’ and ‘highway’ fuel efficiencies are included, as shown below in Figure 4.1.

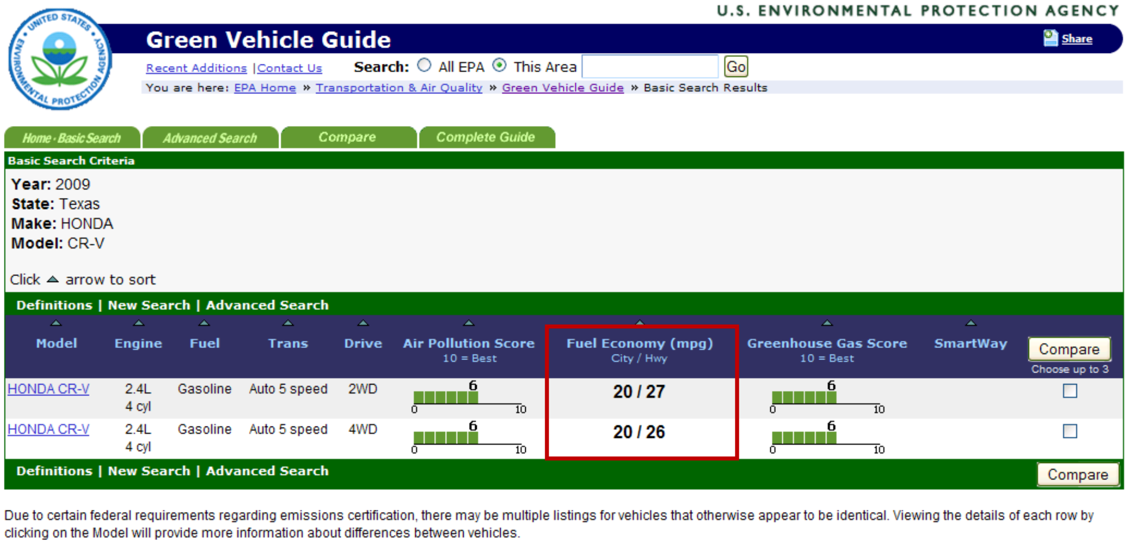

Figure 4.1: Green Vehicle Guide fuel economy (reprinted from *68*).

As shown, the 'city' fuel economy is less than the 'highway' fuel economy, which is expected as highway driving typically includes fewer stops and starts, and typically does not include very low speeds. Weights can be applied to the two values in order to account for different times spent driving in a city setting versus a highway setting. Weights could either be determined per individual based on his or her actual driving, or could be set weights determined by the administrators of the framework. For example, the EPA calculates their combined fuel economy with slightly more weight given to city driving, as shown (Equation 4.1):

$$Combined\ Fuel\ Economy = \frac{1}{0.55/_{City\ Fuel\ Economy} + 0.45/_{Highway\ Fuel\ Economy}} \quad 4.1$$

The *Green Vehicle Guide* only has information on vehicles of model year 2000 or newer. However, fuel economy data are available online for vehicles going back to 1984 through the EPA and the Department of Energy (DOE) (*69*).

4.5: Measure 5—Vehicle Age

Vehicle age affects both emission rates and fuel efficiency. This measure would be needed to determine vehicle fuel efficiency and the air pollution score given by the EPA.

Simply put, this measure would consist of the number of years since the vehicle was manufactured. The vehicle age should be known, as long as the manufacturing year of the vehicle or engine is known.

If the performance measurement system were applied to heavy-duty vehicles, the age of the vehicle would likely be a primary performance measure, as fuel efficiency and emissions ratings are not typically available. For heavy-duty vehicles, the manufacturing year of the engine may be more useful.

4.6: Measure 6—Trips on Transit

The purpose of this measure is to encourage the use of transit, which in turn results in fewer vehicles on the road. Some control should be in place to account for lack of transit options in different areas. It is likely that this measure would not directly affect the mileage-based fee, as transit use does not directly affect a vehicle's emissions, but rather the number of miles driven. One potential use for this measure would be to offer some sort of waiver or decrease to the final amount owed, in order to encourage transit use.

Vehicle classes are not a consideration for this measure, and this measure would not apply to heavy-duty vehicles, as it would typically involve individual travelers. The measure consists of the number of trips taken on transit. To collect such data, an identification system would likely be needed that could keep track of the number of trips an individual has taken. Many transit agencies have fare cards that track trips.

4.7: Measure—Time Traveled At Speed Greater Than Optimal Air Quality Speed

Since traveling above a certain speed increases emissions and fuel consumption, the purpose of this measure is to discourage traveling above an 'optimal speed.' Of course, very low speeds also increase emissions and fuel consumption, but avoiding driving at low speeds may be difficult or impossible for a driver, since low speeds are typically the result of the system rather than driver behavior. In other words, drivers cannot change their behavior to avoid stopping at traffic signals or slowing down in heavy traffic.

Thus, this measure will consist of the percentage of time that the driver is traveling above an optimal speed on a freeway or highway facility per billing period. A typically recognized value of 60 mph is suggested for use as the optimal air quality speed. However, policymakers could change this value if desired, perhaps to reflect higher speed limits in the area. For example, if many of the highways in the priced area had a speed limit of 70 mph, encouraging travel below 60 mph may prove dangerous to drivers. A system such as GPS would be required for this measure, as it would have the ability to record second-by-second speed data, keep track of the total number of seconds where speed exceeded 60 mph, and indicate whether the driver is on a freeway or highway. Alternatively, on-board diagnostic units may be an alternative for collecting second-by-second speed data. If location data were not available, 'highway' travel could be classified as all travel above 50 mph, in which case this measure would determine the percent of time 'highway speed' is above 60 mph, or the chosen optimal speed. For the purpose of this framework, the measure will be calculated as (Equation 4.2):

$$Percent\ Highway\ Speed\ Above\ Optimal = \frac{Total\ Time\ Above\ 60\ mph\ (sec)}{Total\ Time\ Above\ 50\ mph\ (\mathrm{sec})} \times 100 \qquad 4.2$$

4.7.1: Impact of High Speed on Emissions

Although it was known that emissions increase on the highway with higher speeds, the actual impact of this driving behavior was not known. Since these factors figure prominently in the pricing framework, some analysis was undertaken to determine the approximate effect that high speed has on emissions. GPS data from two vehicles driven by TTI employees were used to determine the effect of high speed. Between the two vehicles, 13 speed profiles were identified that included some amount of highway driving, in this case taken to occur when speed was above 50 mph, as exact location was not known. Each speed profile includes second-by-second speed data for a single vehicle-trip. For illustration, graphs of the initial 13 speed profiles are included in Appendix A. Table 4.3 shows a summary of each speed profile.

Table 4.3: Speed Profile Summary

Profile Number	Total Time (sec)	Time Spent over 60 mph (sec)	Highway Time (Time Spent over 50 mph [sec])	Percent 'Highway Time'	Percent of 'Highway Time' over 60 mph
1	805	261	356	44.22%	73.31%
2	969	101	189	19.50%	53.44%
3	636	2	31	4.87%	6.45%
4	1056	72	180	17.05%	40.00%
5	1307	807	955	73.07%	84.50%
6	1266	890	970	76.62%	91.75%
7	1728	22	68	3.94%	32.35%
8	928	16	43	4.63%	37.21%
9	679	16	42	6.19%	38.10%
10	3227	21	411	12.74%	5.11%
11	2871	2003	2098	73.08%	95.47%
12	2960	1907	2069	69.90%	92.17%
13	2318	733	954	41.16%	76.83%
Average	**1596**	**527**	**644**	**34.38%**	**55.90%**

The percent of highway time and the percent of highway driving at speeds greater than 60 mph were calculated in order to evaluate the changes in emissions associated with performance. The emission rates resulting from each speed profile were evaluated using the EPA's emissions modeling program MOVES 2010a.

MOVES can be used to obtain emission rates, as well as total emissions, for many different vehicle types, road types, and pollutants. To obtain emission rates (i.e., grams per mile of pollutant emitted) MOVES is run at the project level, rather than a broader scale such as county or state level. Various inputs that can influence emission rates, such as time of day, time of year, temperature, and vehicle characteristics are selected or entered by the user. Default values that use national-level averages are available for use. Additionally, emissions resulting from different vehicle processes can be calculated, such as emissions from running exhaust, from starting exhaust, or from brake wear. For simplification, only running emissions were accounted for in this research. In addition, the following assumptions were made:

- The run was assumed to be for July 2011, between 11:00 a.m. and noon on a weekday;
- The temperature was assumed to be 95 degrees Fahrenheit, with a relative humidity of 40 percent;
- The vehicle type assumed to be a 2011 model running on gasoline;
- The road type was considered to be urban restricted access, as highway travel was the primary interest;
- Pollutants observed include CO_2, VOC, NOx, CO, total hydrocarbons (THC), $PM_{2.5}$, and SO_2, with only running exhaust emissions used; and
- Only highway driving, with speed greater than 50 mph, was run in MOVES.

The same speed profiles and assumptions were used in MOVES for passenger cars, passenger trucks, and motorcycles, to determine output emission rates. It should be noted that the results are only applicable to light-duty vehicles, since drive patterns are typically different for heavy-duty vehicles. However, the focus of this research is light-duty vehicles only. In addition, it is important to remember that only the effects of high speed was investigated here. In other words, there may be other causes for differences in emission values, but for the purpose of this research, they are assumed to be negligible.

Figure 4.2 shows the resulting emission rates, in grams per mile, for each pollutant type, compared to the percent of highway travel driven at 60 mph or greater.

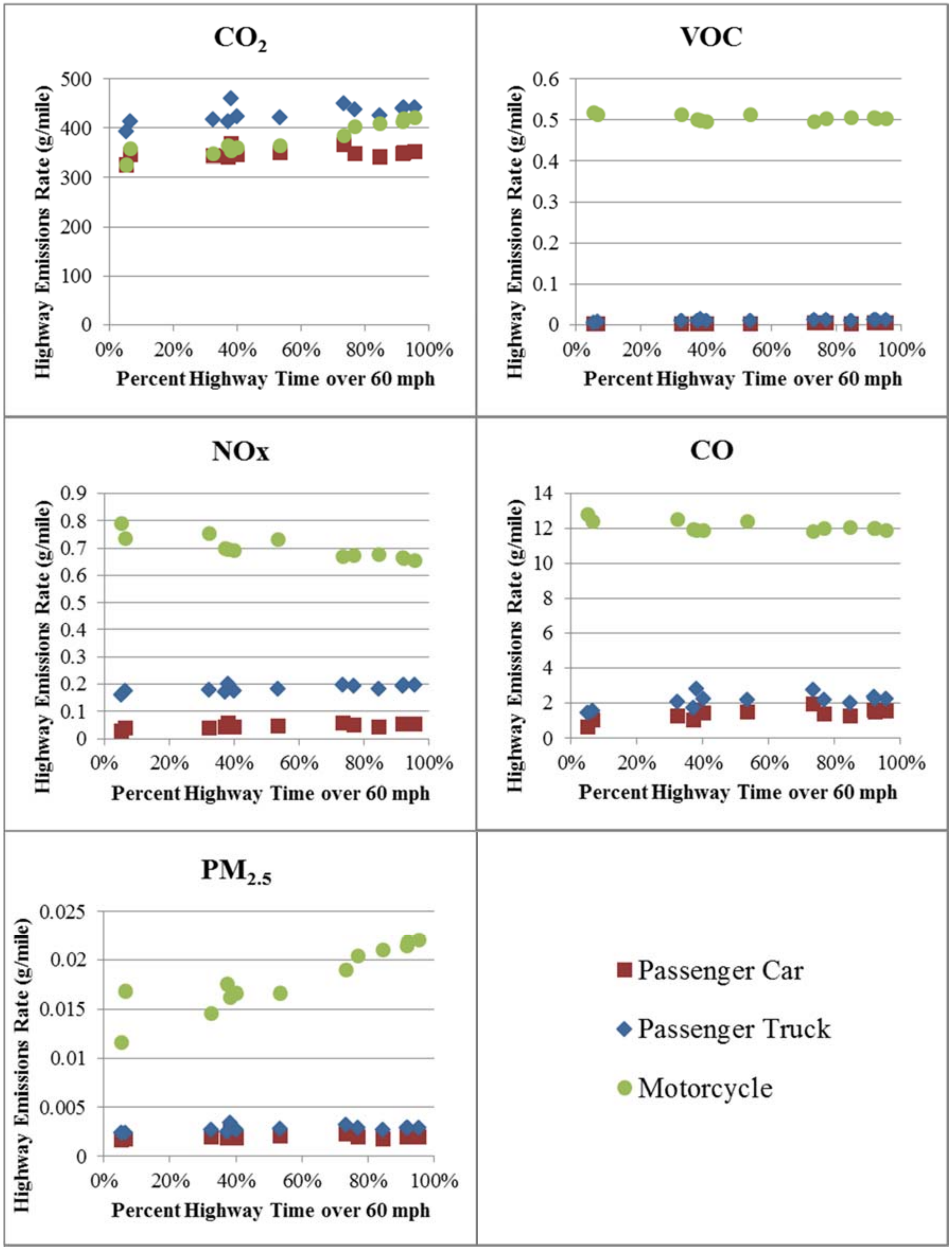

Figure 4.2: Emission rates based on highway speeds over 60 mph.

For all pollutants except CO_2, the emission rates for motorcycles are much higher than for passenger cars and trucks. Figure 4.3 shows emission rates for passenger cars and trucks only, so that the results may be seen more clearly.

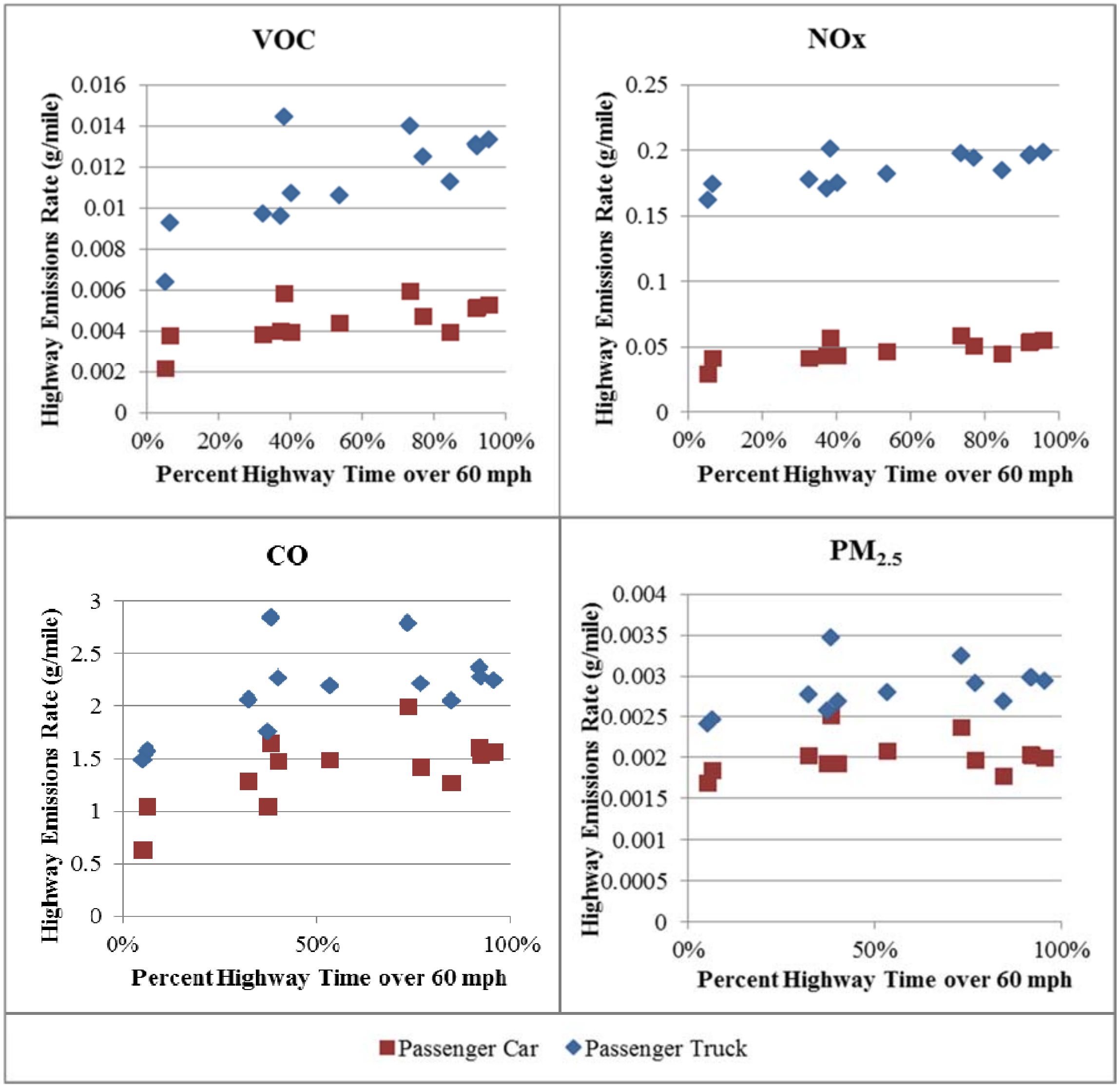

Figure 4.3: Emission rates based on highway speeds over 60 mph for passenger cars and trucks only.

As shown, in general the overall emission rates increase with an increase in the percentage of highway speeds over 60 mph, which is the expected result. The extent of the increase varies depending on the pollutant. The only instance where this does not happen occurs with VOC, NOx, and CO emissions from motorcycles, where the emissions actually decrease with an increased percentage of highway speeds over 60 mph. However, the drive cycles for motorcycles are not necessarily similar to passenger cars and trucks. Performing the analysis with motorcycle GPS data would be desirable. For this research, the above results are assumed to be applicable for motorcycles.

4.8: Measure 8—Time Spent Aggressively Accelerating/Braking

Driving aggressively increases emissions and fuel consumption. For simplicity, 'aggressive driving' will be defined as hard acceleration or deceleration in this measure. This measure is represented as the percentage of time that a threshold acceleration or deceleration value is exceeded by the vehicle. To determine the threshold values used in this framework, second-by-second speed data collected by TTI employees was used. The 85th percentile acceleration value was chosen to represent 'hard' acceleration. Similarly, the 85th percentile deceleration value was chosen to represent 'hard' braking. In addition, different levels of acceleration/deceleration are required depending on what speed the vehicle is driving. Therefore, different threshold values were determined for speeds between 5 and 25 mph, speeds between 25 and 50 mph, and speeds above 50 mph. Speeds below 5 mph were not included in determining the 85th percentile threshold, as hard acceleration often occurs when starting from a stopped position. The threshold acceleration values and threshold deceleration values obtained are shown in Table 4.4, as well as the rounded values that were used.

Table 4.4: Threshold (85th Percentile) Acceleration/Deceleration Values

Speed	Subject 1	Subject 2	Average	Use:
Acceleration				
0 to 25 mph	3.1 mph/s	2.7 mph/s	2.9 mph/s	**3.5 mph/s**
5 to 25 mph	3.8 mph/s	3.3 mph/s	3.55 mph/s	
25 to 50 mph	2.0 mph/s	1.8 mph/s	1.9 mph/s	**2 mph/s**
Greater than or equal to 50 mph	1.0 mph/s	0.6 mph/s	0.8 mph/s	**1 mph/s**
Deceleration				
0 to 25 mph	-3.7 mph/s	-2.8 mph/s	-3.3 mph/s	**-3.5 mph/s**
5 to 25 mph	-4.3 mph/s	-3.0 mph/s	-3.65 mph/s	
25 to 50 mph	-1.8 mph/s	-1.8 mph/s	-1.8 mph/s	**-2 mph/s**
Greater than or equal to 50 mph	-1.0 mph/s	-0.6 mph/s	-0.8 mph/s	**-1 mph/s**
*where mph is miles per hour and mph/s is miles per hour per second				

For the purpose of this research, these values are assumed to apply to all light-duty vehicle types. However, the same analysis should be performed for light-duty passenger trucks and for motorcycles separately, if possible, as the drive cycles are not necessarily similar to light-duty passenger cars.

The performance measure would track the total time where acceleration or deceleration was greater than these threshold value, depending on the speed the vehicle is traveling, on a second-by-second basis. The final measure would be calculated as a percentage of the total driving time, as shown below (Equation 4.3):

$$Percent\ Hard\ Acceleration/Deceleration = \frac{\sum_{i=1}^{3} time\ in\ seconds\ acceleration/decel\ exceeds\ threshold\ for\ speed\ range\ i}{Total\ Time\ (\text{sec})} \times 100 \qquad 4.3$$

The speed ranges would include speeds of 0 to 25 mph, 25 to 50 mph, and greater than 50 mph.

4.8.1: Impact of Hard Acceleration/Braking on Emissions

As with high speed driving, the exact impact of this aggressive driving behavior was not known. Additional analysis was undertaken to determine the approximate effect that hard acceleration/braking has on emissions, using the same speed profiles as the previous section, along with an additional 17 speed profiles that did not include any highway driving. Table 4.5 shows a summary of each speed profile.

Table 4.5: Acceleration Profile Summary

Profile Number	Total Time (sec)	Time With Non-Zero Acceleration/ Deceleration	Time With Positive Non-Zero Acceleration	Time With 'Hard' Acceleration/ Deceleration	Time With 'Hard' Positive Acceleration	Percent of 'Hard' Acceleration/ Deceleration	Percent of 'Hard' Positive Acceleration
1	805	744	378	168	82	22.58%	21.69%
2	969	775	391	306	163	39.48%	41.69%
3	636	521	273	211	103	40.50%	37.73%
4	1056	732	366	229	109	31.28%	29.78%
5	1307	1107	559	146	75	13.19%	13.42%
6	1266	1130	581	141	72	12.48%	12.39%
7	1728	1119	587	437	224	39.05%	38.16%
8	928	618	337	194	103	31.39%	30.56%
9	679	548	296	132	72	24.09%	24.32%
10	3227	2107	1029	591	267	28.05%	25.95%
11	2871	2539	1336	202	102	7.96%	7.63%
12	2960	2699	1375	253	126	9.37%	9.16%
13	2318	1864	929	404	191	21.67%	20.56%
14	1471	1200	605	282	143	23.50%	23.64%
15	504	412	222	217	114	52.67%	51.35%
16	601	454	234	198	106	43.61%	45.30%
17	1086	777	380	236	114	30.37%	30.00%
18	499	465	240	137	68	29.46%	28.33%
19	434	391	177	148	74	37.85%	41.81%
20	1464	1049	546	269	143	25.64%	26.19%
21	702	528	243	200	89	37.88%	36.63%
22	1420	765	368	336	171	43.92%	46.47%
23	353	333	175	201	109	60.36%	62.29%
24	330	310	149	201	97	64.84%	65.10%
25	4346	3874	2019	112	78	2.89%	3.86%
26	334	317	152	199	95	62.78%	62.50%
27	501	485	244	352	183	72.58%	75.00%
28	426	419	214	350	182	83.53%	85.05%
29	386	381	194	347	181	91.08%	93.30%
30	469	454	231	354	184	77.97%	79.65%
Average	**1203**	**971**	**494**	**252**	**127**	**38.73%**	**38.98%**

As shown in the table, the percent of hard acceleration and deceleration tends to be fairly similar to the percent of hard positive acceleration only in each speed profile.

These 30 speed profiles were run with the EPA MOVES program, with similar assumptions as used in the previous section. The full speed profiles were run, including non-highway travel. Figure 4.4 shows the resulting emission rates, in grams per mile, for each pollutant type. The emission rates is plotted against the independent variable of percent hard acceleration and deceleration.

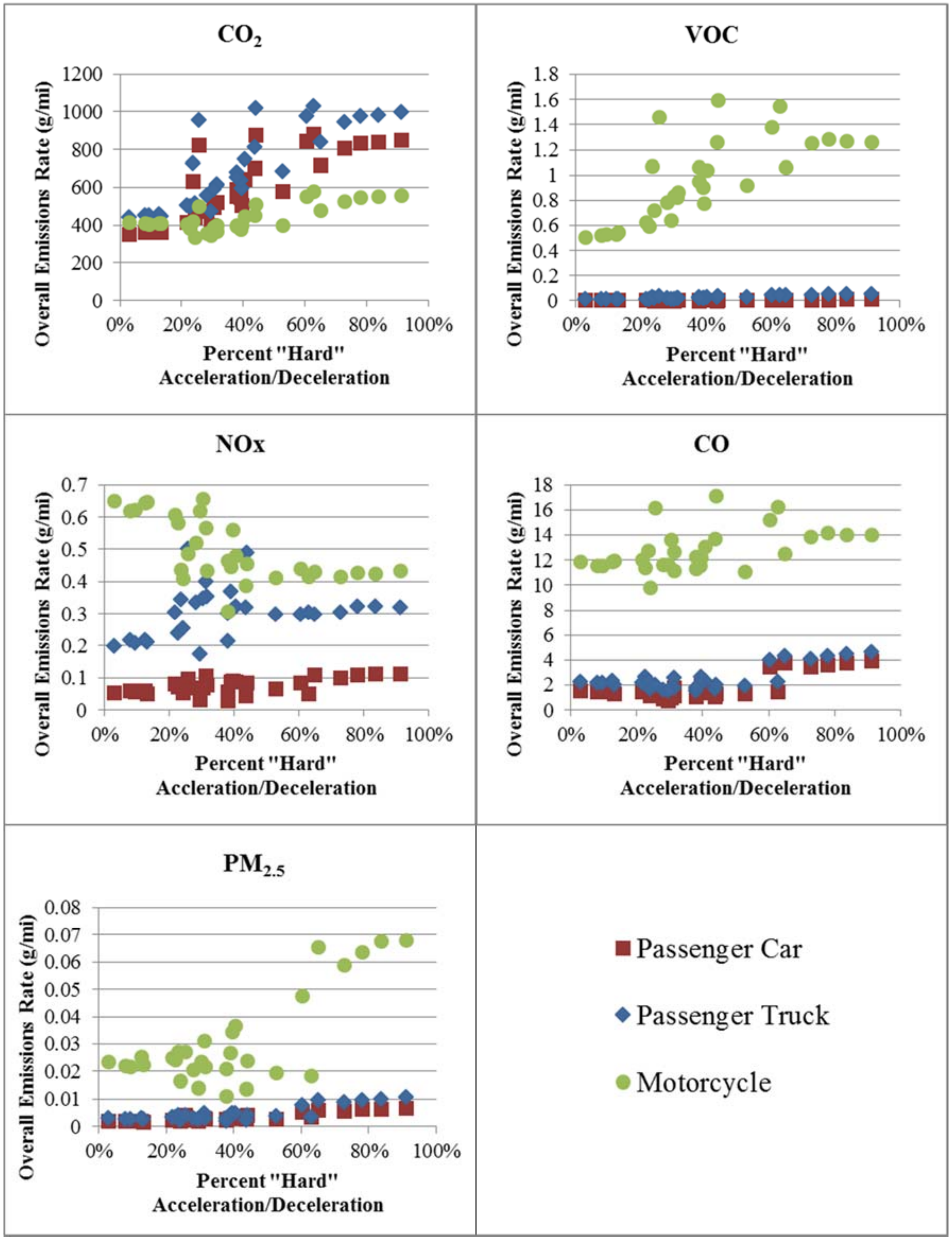

Figure 4.4: Emission rates based on hard acceleration/deceleration.

Again, not all of the data can be clearly seen due to the higher scale of emissions for motorcycles, with the exception of the graph for CO_2. Figure 4.5 shows results more clearly for passenger cars and trucks.

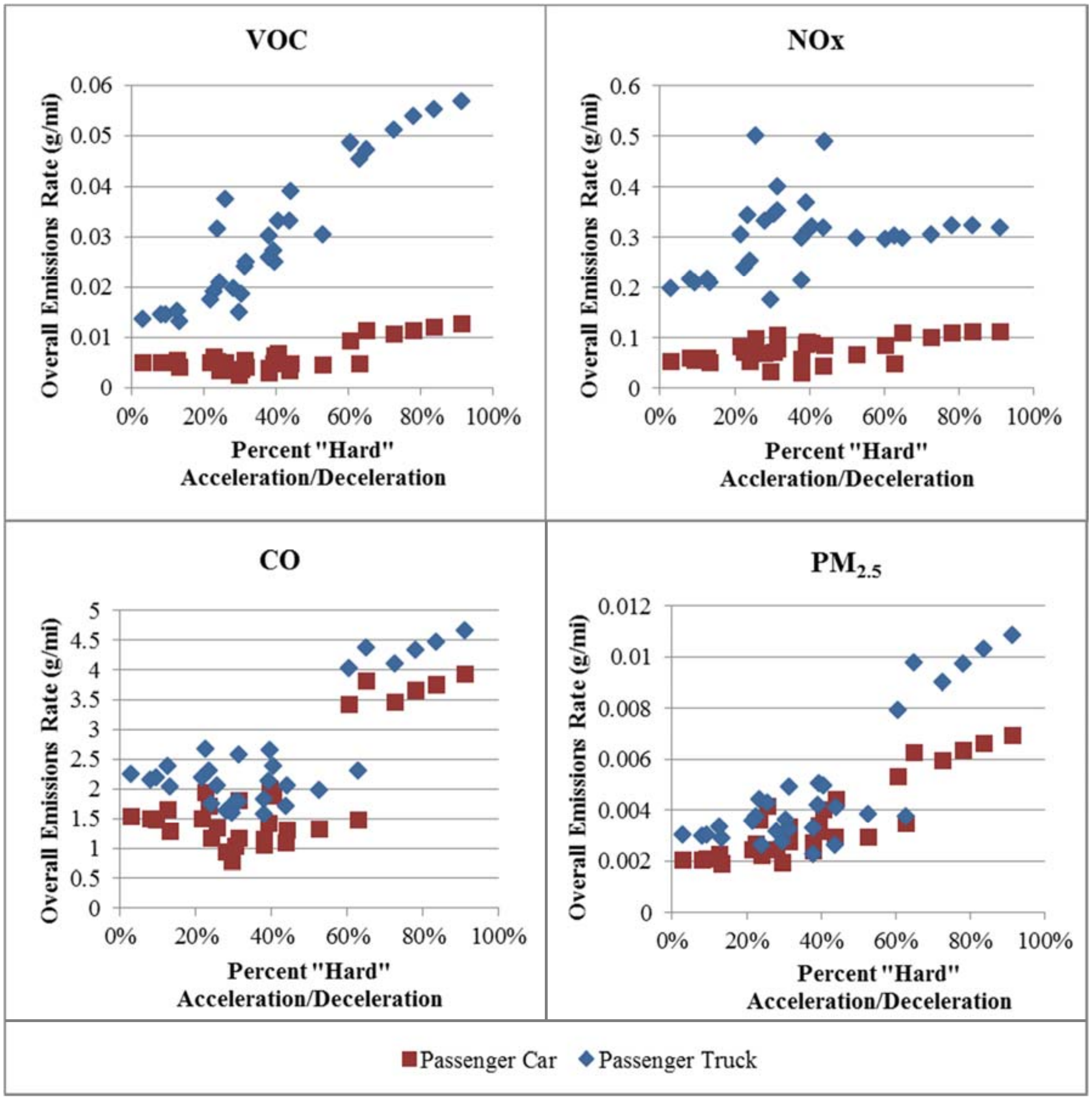

Figure 4.5: Emission rates based on hard acceleration/deceleration for passenger cars and trucks only.

Figure 4.5 shows how, in general, the overall emission rates increases when the percent of hard acceleration and deceleration increases. This positive relationship holds true for all pollutant types, although the amount of increase varies. The only instance where this does not happen occurs with NOx emissions from motorcycles, where the emissions actually decrease with greater hard acceleration/deceleration. However, the drive cycles for motorcycles are not necessarily similar to passenger cars and trucks. Performing the analysis with motorcycle GPS data would be desirable. For this research, this result is assumed to be applicable for motorcycles.

4.9: Measure 9—Driver Training

The idea behind this measure is to encourage drivers to learn how to drive in a more eco-friendly way. While the training may not a have a significant effect on emissions, it may encourage drivers to be more aware of how they are driving. In addition, some of the other measures may be confusing to the public, and such training could help to keep the public up to date about ways to increase their performance and pay less per mile. One study found fuel savings of about 5 percent with eco-driving training, and about 10 percent with both training and some sort of continuous feedback (*70*). Like the transit measure (Measure 6), this measure would not likely directly impact the mileage-based fee, but could result in some reduction of the final amount owed. The measure would consist of whether the individual participated in training or not. Such training could be a one-time class, or could be renewed on a yearly basis. If such a training program were implemented, it would likely be online, similar to existing defensive driving programs. A user could even potentially log into the account where they pay their mileage fee, take the training there, and the site could log that they had completed it.

4.10: Concluding Remarks

The performance measures selected for use in this research were further defined in this section. Some measures relate specifically to characteristics of the vehicle, including vehicle age, fuel economy, and emissions rating. Others relate to actions taken by the individual, such as amount driven, driving behavior, and use of transit or training. The approximate effect of 'aggressive driving' behaviors was illustrated in order to better define the relationship between these driving behaviors and air quality impacts. These impacts of high speed and hard acceleration/deceleration on emissions will be utilized in the next section.

While odometer readings could be used for simple mileage, many of the other measures require some sort of technology component for data collection, such as GPS or on-board diagnostic units. Therefore, calculation of most measures would depend on the technology available. The 'aggressive driving' measures would certainly require some technology component.

The next section will illustrate how performance on these measures will be used to calculate approximate emission rates, which will then be used to develop a final performance score.

5. COMBINING PERFORMANCE MEASURES

5.1: Overview

The performance measures developed for this research are used in different ways. Vehicle mileage is used primarily as a means of determining the final fee due, as a mileage-based fee is applied directly to mileage. However, some mileage may be charged at a higher rate, such as mileage occurring during peak hours. Such criteria can be selected as needed. Additionally, measures such as trips on transit or participation in eco-driving training do not have a direct impact on vehicle emissions, and are best not applied directly in determining the mileage fee. A suggested application for these measures would be as waivers or reductions in the final amount owed by the user.

However, some measures developed for this research affect vehicular emission rates in a much more direct way. These measures are useful for determining the mileage-fee that should be charged to a particular user and will be addressed in this section. Vehicle classification and age will be used to determine baseline emission rates for CO_2, VOC, NO_x, CO, and $PM_{2.5}$. Performance on the other measures (vehicle emissions rating, fuel efficiency, and driving behaviors) will be used to scale up or scale down an individual's emission rates. The final emission rates will be used to determine performance scores for each pollutant based on anticipated distributions of results. A final performance score can be calculated by combining scores for individual pollutants.

5.2: MOVES Baseline Emission Rates

Emission rates are the amount of pollutant emitted by a vehicle per mile. Performance Measure 5, Vehicle Age, is used to determine baseline emission rates for an individual vehicle, in addition to vehicle class. For simplification, vehicle model years were grouped into several strata: 2010+, 2007-2009, 2004-2006, 2000-2003, 1996-1999, 1992-1995, 1988-1991, and pre-1988. Baseline emission rates for these model years and for each vehicle class were calculated using the EPA's MOVES program.

To determine baseline emission rates, national averages provided by the program were used when available, including national-level operating mode distributions. For simplification, the following assumptions were used:

- The run was assumed to be for July 2011, between 11:00 a.m. and noon on a weekday, in Texas;
- The temperature was assumed to be 88.5 degrees Fahrenheit, with a relative humidity of 55.6 percent;
- Light-duty vehicles were assumed to use gasoline;
- Vehicle model years ranged from 1981 to 2011;
- The road types used were urban restricted access and urban unrestricted access;
- Average speeds of 35 mph for the unrestricted access facility and 60 mph for the restricted access facility were used; and
- Pollutants observed include CO_2, VOC, NOx, CO, THC, $PM_{2.5}$, and SO_2, with only running exhaust emissions used.

Results were averaged for each vehicle class and vehicle age bin. The two rates obtained for the restricted access facility and the unrestricted access facility were averaged to determine the final base rates that would be used for each vehicle class. These final rates represent a very general estimate. Tables 5.1 through 5.3 show the calculated base rates for each vehicle class.

Table 5.1: MOVES Base Emission Rates for Passenger Cars

Model Year	**Averaged Pollutant Rate in g/mile on Urban Facilities**				
	CO_2	**VOC**	**NOx**	**CO**	**$PM_{2.5}$**
2010+	475.616	0.004	0.034	0.877	0.002
2007-2009	470.543	0.006	0.053	1.244	0.002
2004-2006	478.110	0.016	0.140	2.709	0.003
2000-2003	476.155	0.093	0.678	4.902	0.004
1996-1999	468.423	0.305	1.280	8.338	0.007
1992-1995	463.843	0.605	2.227	13.512	0.013
1988-1991	468.373	0.970	2.584	19.807	0.026
pre-1988	529.564	1.671	2.622	32.990	0.037

Table 5.2: MOVES Base Emission Rates for Passenger Trucks

Model Year	Averaged Pollutant Rate in g/mile on Urban Facilities				
	CO_2	VOC	NOx	CO	$PM_{2.5}$
2010+	586.547	0.024	0.181	1.398	0.003
2007-2009	630.073	0.026	0.202	1.814	0.003
2004-2006	671.450	0.071	0.388	3.803	0.004
2000-2003	663.515	0.251	1.320	8.892	0.005
1996-1999	629.306	0.517	1.960	13.845	0.008
1992-1995	583.763	1.518	4.277	28.485	0.021
1988-1991	608.585	2.013	4.640	39.157	0.034
pre-1988	707.104	3.149	4.582	59.566	0.060

Table 5.3: MOVES Base Emission Rates for Motorcycles

Model Year	Averaged Pollutant Rate in g/mile on Urban Facilities				
	CO_2	VOC	NOx	CO	$PM_{2.5}$
2010+	376.323	0.838	0.418	9.278	0.016
2007-2009	376.323	1.060	0.428	11.092	0.016
2004-2006	376.323	1.506	0.447	14.718	0.016
2000-2003	376.323	1.873	0.592	20.000	0.016
1996-1999	368.855	1.746	0.565	19.281	0.016
1992-1995	352.100	1.725	0.570	18.778	0.016
1988-1991	331.871	1.712	0.575	18.270	0.016
pre-1988	328.525	2.820	0.652	23.129	0.016

For reference, the emission rates for both speeds are provided in Appendix B.

The base emission rates for an individual are selected based on vehicle class and model year. These rates are then scaled up or down based on other performance measures for each individual, including vehicle emissions rating, fuel efficiency, percentages of highway speeds over 60 mph, and hard acceleration/deceleration. The next section describes the derivation of scaling factors for each performance measure that will be applied to the baseline emission rates.

5.3: Turning Performance into Scaling Factors

In order to determine how performance on these measures should affect the mileage fee, it was desirable to determine how performance would affect emission rates. An individual's performance on each measure could then be used to scale a base emission rates up or down. The final emission rates could then be compared to anticipated emission rates across the system to determine a performance score.

5.3.1: Measure 3 – Vehicle Emissions Rating

The purpose of Measure 3 is to offer an advantage for vehicles that emit fewer emissions. Therefore, performance on this measure can be used to scale down the vehicle's emission rates. However, poor performance on this measure (i.e., a high emitting vehicle) will not scale up the vehicle's emission rates. This is because the EPA standards that relate to the vehicle emissions rating framework are only given as maximum allowed grams per mile of certain pollutants, which is the emission amount the vehicle is certified to not exceed. The vehicle may not necessarily have such high emissions on average. Thus, without more detailed information, we assume that this measure can only be advantageous to the user.

For this research, the Federal Tier 2 standards will be used, rather than the more stringent Low Emission Vehicle (LEV) II standards used in California. The Federal Tier 2 standards give maximum allowed grams per mile for different air pollution 'scores,' which are on a scale of zero to ten, with ten as a 'zero-emission' vehicle. These standards are given for NOx, CO, PM, non-methane organic gas (NMOG), and formaldehyde (HCHO). For this research, the standards for NOx, CO, and PM are used, with the assumption that the PM standards apply to $PM_{2.5}$. Baseline emission rates were not obtained with MOVES for NMOG or HCHO. Additionally, there are two different standards for an air pollution score of one, dependent on vehicle weight. Table 5.4 shows the standards used in this research.

Table 5.4: Federal Tier 2 Emission Standards Based on EPA Air Pollution Score (Maximum Allowed Grams per Mile)

Air Pollution Score	Pollutant			Applicable Vehicle Type
	NOx	CO	PM	
10	0	0	0	All Light-Duty
9	0.02	2.1	0.01	All Light-Duty
8	0.03	2.1	0.01	All Light-Duty
7	0.04	2.1	0.01	All Light-Duty
6	0.07	4.2	0.01	All Light-Duty
5	0.1	4.2	0.01	All Light-Duty
4	0.15	4.2	0.02	All Light-Duty
3	0.2	4.2	0.02	All Light-Duty
2	0.3	4.2	0.06	All Light-Duty
1	0.6	4.2	0.08	LDV, LLDT
	0.6	6.4	0.08	HLDT, MDPV
0	0.9	7.3	0.12	MDPV

The vehicle types included in the above table are light-duty vehicles (LDV) or passenger cars, light light-duty trucks (LLDT) that are trucks up to 6000 pounds GVWR, heavy light-duty trucks (HLDT) that are trucks between 6001 and 8500 pounds GVWR, and medium-duty passenger vehicles (MDPV) that are trucks between 8501 and 10,000 pounds GVWR. The Tier 2 standards used are also only applicable for vehicle model years 2004 and newer.

For this performance measure, these standards are used to decrease the vehicle's emissions, if applicable, to account for vehicles that perform better than the base vehicle. In other words, in the cases where the Federal Tier 2 Standard maximum allowed emission rate (in g/mile) was less than the MOVES base emission rate, a scaling factor would be used to decrease that vehicle's base emission rates to the maximum allowed rate. Thus, the scaling factor would be calculated as (Equation 5.1):

$$Scaling\ Factor_{Measure\ 3} = \frac{Federal\ Tier\ 2\ Standard\ Maximum\ Allowed\ g/mi}{Base\ Emission\ Rate\ g/mi} \qquad 5.1$$

If the Federal Tier 2 Standard maximum allowed rate is greater than the base rate, the scaling factor would equal one. For the air pollution score, only vehicles that are 2004 model year or newer are considered, as these are the vehicles to which the Federal Tier 2 standards apply. Therefore, without further emission information, baseline emission rates for older vehicles remain unchanged by this measure. The scaling factors for passenger cars and trucks resulting from this process are shown in Table 5.5.

Table 5.5: Scaling Factors Based on Air Pollution Score

Vehicle Class	Vehicle Model Year	Air Pollution Score	Pollutant		
			NOx	CO	PM
Passenger Car	2010+	10	0	0	0
		9	0.5856	-	-
		8	0.8784	-	-
	2007-2009	10	0	0	0
		9	0.3771	-	-
		8	0.5657	-	-
		7	0.7543	-	-
	2004-2006	10	0	0	0
		9	0.1431	0.7752	-
		8	0.2147	0.7752	-
		7	0.2862	0.7752	-
		6	0.5009	-	-
		5	0.7156	-	-
Passenger Truck	2010+	10	0	0	0
		9	0.1104	-	-
		8	0.1655	-	-
		7	0.2207	-	-
		6	0.3863	-	-
		5	0.5518	-	-
		4	0.8277	-	-
	2007-2009	10	0	0	0
		9	0.0988	-	-
		8	0.1482	-	-
		7	0.1976	-	-
		6	0.3457	-	-
		5	0.4939	-	-
		4	0.7409	-	-
		3	0.9878	-	-
	2004-2006	10	0	0	0
		9	0.0516	0.5522	-
		8	0.0774	0.5522	-
		7	0.1032	0.5522	-
		6	0.1805	-	-
		5	0.2579	-	-
		4	0.3868	-	-
		3	0.5158	-	-
		2	0.7737	-	-

*Note: Dashes are used when the maximum allowed EPA standard was greater than the baseline emissions rate; in this case the scaling factor would be 1.0.

Scaling factors for this measure are most applicable for NOx, as the obtained MOVES base rates exceed the standards for NOx for most of the available vehicle models since 2004. MOVES base rates are already below standards for most air pollution scores for these vehicles. This is expected, as the standards are given as the maximum allowable, so the emissions for the vehicle should not exceed that amount. The maximum allowable NOx emissions has the most variability for the different Air Pollution scores. Additionally, it should be noted that an air pollution score of ten represents a 'zero-emission' vehicle, resulting in a scaling factor of zero.

5.3.2: Measure 4 – Vehicle Fuel Economy

For Measure 4, either the average fuel economy or the EPA greenhouse gas score could be used. However, the greenhouse gas score is only available for vehicles from 2000 and newer. The approximate emissions of CO_2 per gallon of fuel burned for several different fuel types are shown below in Table 5.6 (*71*).

Table 5.6: Carbon Dioxide Emissions from Fuel Combustion

Fuel Type	**Grams CO_2 per Gallon**
Gasoline	8,910
Diesel	10,150
Ethanol Blend (E85)	1,340

To determine the emissions per mile for a vehicle based on average fuel economy, the grams per gallon of CO_2 would be divided by the fuel economy, as shown in Equation 5.2.

$$CO_2\left(\frac{g}{mile}\right) = \frac{CO_2\ per\ gallon\ of\ fuel}{Fuel\ Economy\ (miles/gallon)} \qquad 5.2$$

The resulting CO_2 rate per mile is used to adjust the vehicle's base emission rate, as with the air pollution score.

The scaling factors for fuel efficiency performance are calculated in a similar manner as for vehicle emissions rating, comparing grams of CO_2 per mile based on an individual vehicle's fuel economy to base rate CO_2 emissions; thus, the scaling factor would be calculated as (Equation 5.3):

$$Scaling\ Factor_{Measure\ 4} = \frac{g/mi\ of\ CO_2\ from\ fuel\ economy}{Base\ Emission\ Rate\ of\ CO_2\ in\ g/mi} \qquad 5.3$$

The scaling factor is used to increase or decrease a vehicle's base emission rate of CO_2 to reflect the characteristics of an individual vehicle. As an example, the scaling factor for a 2008 gasoline vehicle with an average fuel economy of 25 miles per gallon is shown in Equation 5.4.

$$Scaling\ Factor_{Measure\ 4} = \frac{CO_2\ (\frac{g}{gallon}) \Big/ fuel\ economy\ (\frac{mi}{gallon})}{Base\ Emission\ Rate\ of\ CO_2\ in\ g/mi} \qquad 5.4$$

$$= \frac{8{,}910\ g/gallon \big/ 30\ mi/gallon}{470.543\ g/mi} = \frac{356.4\ g/mi}{470.543\ g/mi} = 0.7574$$

It should be noted that the actual fuel economy achieved may vary among different drivers, even with the same vehicle. However, the subsequent performance measures attempt to account for differences in driving behavior which may affect the fuel economy of a vehicle.

5.3.3: Measure 7 – Time Traveled at Speed Greater Than Optimal Air Quality Speed

The purpose of Measure 7 is to discourage high speed driving, which increases emission rates. Performance on this measure can be used to scale up the vehicle's base emission rates. The emission rates based on percent highway speed presented in the previous section (Section 4.7) were normalized to the lowest value to see how much emissions would be increased based on performance. Figure 5.1 shows the resulting normalized results along with trend lines fit to the data.

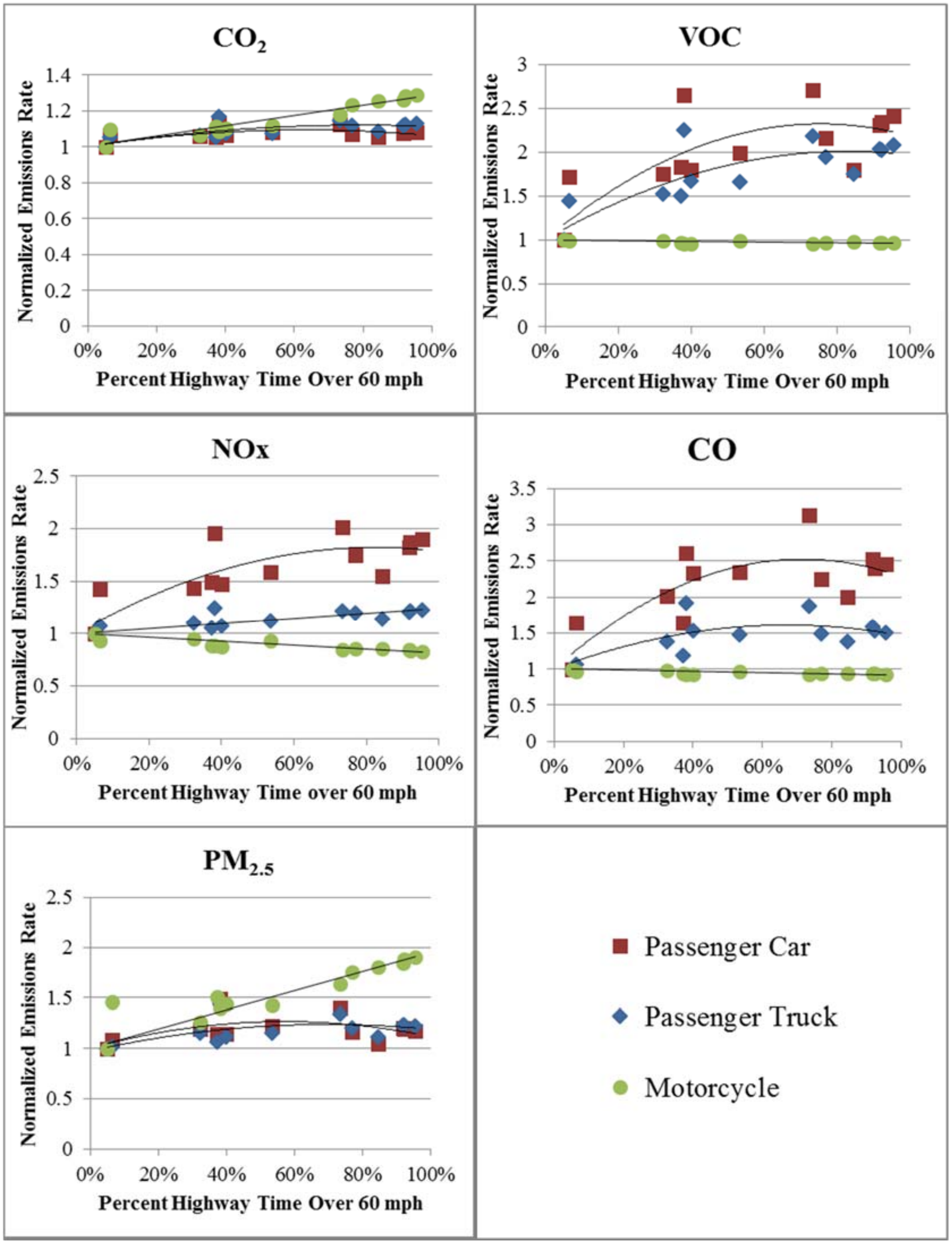

Figure 5.1: Normalized emission rates based on highway speeds over 60 mph.

Many of the trend lines used were second-order polynomials, which tended to fit the data fairly well. Where the squared term was negligible and the R^2 value was not improved by using a second-order polynomial, a linear equation was used for simplicity. In addition, it was assumed that a performance of driving zero percent above 60 mph on the freeway would not increase the baseline emission rates for the individual—thus, the y-intercepts were all set to equal one. Table 5.7 shows the equations used for each trend line, along with the R^2 values.

Table 5.7: Trend Line Equations Used for Normalized Emission Rates Based on Highway Speeds over 60 mph

Pollutant	Vehicle Class	Equation*	R-Squared Value
CO_2	Passenger Car	$y = -0.2343x^2 + 0.2953x + 1$	$R^2 = 0.3131$
	Passenger Truck	$y = -0.1904x^2 + 0.3026x + 1$	$R^2 = 0.4908$
	Motorcycle	$y = 0.2857x + 1$	$R^2 = 0.8981$
VOC	Passenger Car	$y = -2.321x^2 + 3.5064x + 1$	$R^2 = 0.4839$
	Passenger Truck	$y = -1.4614x^2 + 2.4306x + 1$	$R^2 = 0.5972$
	Motorcycle	$y = 0.0842x^2 – 0.1084x + 1$	$R^2 = 0.4142$
NOx	Passenger Car	$y = -1.211x^2 + 1.9954x + 1$	$R^2 = 0.5643$
	Passenger Truck	$y = 0.2417x + 1$	$R^2 = 0.5315$
	Motorcycle	$y = -0.19x + 1$	$R^2 = 0.6306$
CO	Passenger Car	$y = -2.986x^2 + 4.2662x + 1$	$R^2 = 0.6054$
	Passenger Truck	$y = -1.348x^2 + 1.8112x + 1$	$R^2 = 0.5165$
	Motorcycle	$y = -0.0848x + 1$	$R^2 = 0.093$
$PM_{2.5}$	Passenger Car	$y = -0.8133x^2 + 0.9295x + 1$	$R^2 = 0.3052$
	Passenger Truck	$y = -0.5425x^2 + 0.7576x + 1$	$R^2 = 0.3747$
	Motorcycle	$y = 0.9526x + 1$	$R^2 = 0.7730$
*Where y is the normalized emission rate and x is the percent of highway time over 60 mph			

The above trend lines were assumed to be an accurate representation for the three light-duty vehicle categories. The resulting normalized emission rate (‘y’) would be used as a scaling factor to increase the base emission rates of an individual vehicle based on the individual’s performance on Measure 7, Time Traveled at Greater Than Optimal Air

Quality Speed ('x'). It should be noted that emissions of VOC, NO_x, and CO decrease for motorcycles with a higher percent of highway time over 60 mph.

Table 5.8 shows possible scaling factors for a passenger car based on differing levels of performance. The following equation shows how the scaling factor for CO_2 would be calculated using the above equations and assuming 40 percent of highway driving over 60 mph, as an example (Equation 5.5):

$$Scaling\ Factor\ for\ Measure\ 7_{CO_2} = (-0.2343 \times 0.40^2) + (0.2953 \times 0.40) + 1 = 1.081 \quad 5.5$$

Table 5.8: Example Scaling Factors Based on Percent of Highway Speed Over 60 mph

Percent Highway Speed Greater Than 60 mph	Scaling Factor for Each Pollutant Based on Performance for Passenger Car				
	CO_2	VOC	NOx	CO	$PM_{2.5}$
0%	1	1	1	1	1
20%	1.050	1.608	1.351	1.734	1.153
40%	1.081	2.031	1.604	2.229	1.242
60%	1.093	2.268	1.761	2.485	1.265
80%	1.086	2.320	1.821	2.502	1.223
100%	1.061	2.185	1.784	2.280	1.116

Finally, since this performance measure only affects emission rates for highway travel, these scaling factors will only be applied to the portion of emission rates that occur on highway facilities. A simple equation used to calculate this is (Equation 5.6):

$$New\ Emission\ Rate = Base\ Rate \times \left(\%Nonhighway + (\%Highway) \times (Scaling\ Factor_{Measure\ 7})\right) \quad 5.6$$

For example, if half of the travel occurred on highway facilities and the scaling factor were 2, then the new emission rates would be 1.5 times greater than the base rate. For the purposes of this research, non-highway speeds were not accounted for within the performance measurement system. Non-highway speed is more likely to be affected by factors outside of the driver's control, such as frequency of traffic signals.

5.3.4: Measure 8 – Time Spent with 'Hard' Accelerating/Braking

The purpose of Measure 8 is to discourage hard acceleration and hard deceleration/braking, which increases emission rates. The 85th percentile acceleration and deceleration values shown in Table 4.4 were used in this research to represent hard acceleration/deceleration. Performance on this measure can be used to scale up the vehicle's base emission rates. The results presented in the previous section (Section 4.8) were normalized to the lowest value to see how much emissions would be increased based on performance. Figure 5.2 shows the resulting normalized emission rates along with trend lines fit to the data.

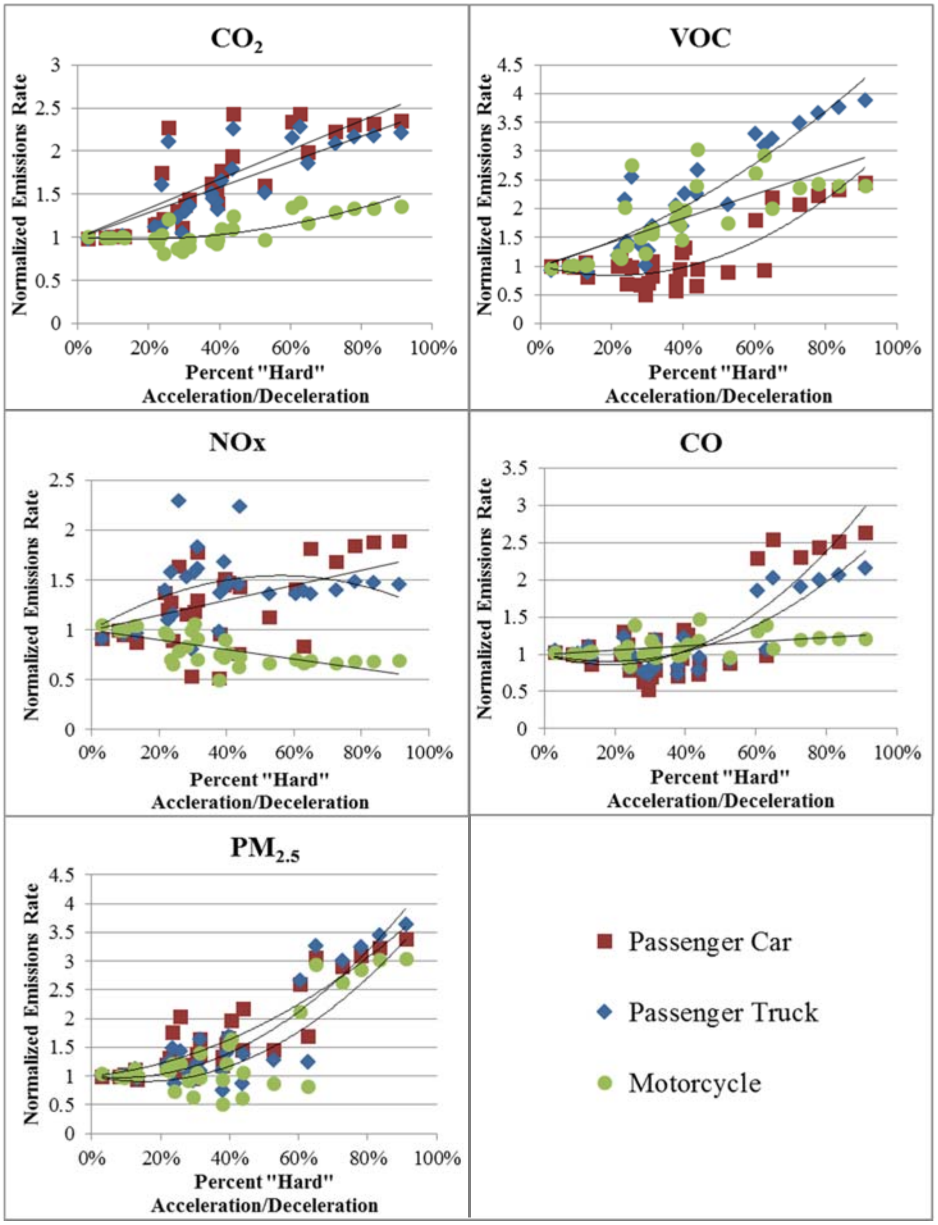

Figure 5.2: Normalized emission rates based on hard acceleration/deceleration.

Again, the trend lines were all set with a y-intercept of one. Many of the trend lines are second-order polynomials, but as with the high speed data, linear trend lines were used when the x-squared factor was negligible and the R^2 value was not improved by using a second-order polynomial. Table 5.9 shows the equations used for each trend line, along with the R^2 values.

Table 5.9: Trend Line Equations Used for Normalized Emission Rates Based on Hard Acceleration/Deceleration

Pollutant	Vehicle Class	Equation*	R-Squared Value
CO_2	Passenger Car	$y = 1.6881x + 1$	$R^2 = 0.6906$
	Passenger Truck	$y = 1.4689x + 1$	$R^2 = 0.6902$
	Motorcycle	$y = 0.8828x^2 - 0.2765x + 1$	$R^2 = 0.6160$
VOC	Passenger Car	$y = 3.7902x^2 - 1.572x + 1$	$R^2 = 0.7637$
	Passenger Truck	$y = 2.0143x^2 + 1.7534x + 1$	$R^2 = 0.8575$
	Motorcycle	$y = 2.0651x + 1$	$R^2 = 0.5348$
NOx	Passenger Car	$y = 0.7479x + 1$	$R^2 = 0.3107$
	Passenger Truck	$y = -1.7344x^2 + 1.943x + 1$	$R^2 = 0.2223$
	Motorcycle	$y = -0.4855x + 1$	$R^2 = 0.4290$
CO	Passenger Car	$y = 4.0566x^2 - 1.5161x + 1$	$R^2 = 0.7312$
	Passenger Truck	$y = 2.8106x^2 - 1.0374x + 1$	$R^2 = 0.7481$
	Motorcycle	$y = 0.2831x + 1$	$R^2 = 0.2350$
$PM_{2.5}$	Passenger Car	$y = 2.4678x^2 + 0.6009x + 1$	$R^2 = 0.8155$
	Passenger Truck	$y = 4.2845x^2 - 0.7051x + 1$	$R^2 = 0.8038$
	Motorcycle	$y = 4.2559x^2 - 1.2711x + 1$	$R^2 = 0.7194$
*Where y is the normalized emission rate and x is the percent of hard acceleration/deceleration			

The scaling factors used for this performance measure are determined by the above trend line equations. As with the previous performance measure, zero percent hard acceleration/deceleration would result in a scaling factor of one, and thus would not increase the baseline emission rates for the individual.

Table 5.10 shows possible scaling factors for a passenger car as they relate to different levels of performance. The following equation shows how the scaling factor for VOC would be calculated using the above equations and assuming 60 percent hard acceleration/deceleration, as an example (Equation 5.7.):

$$Scaling\ Factor\ for\ Measure\ 8_{VOC} = (3.7902 \times (0.60)^2) - (1.572 \times 0.60) + 1 = 1.421 \quad 5.7$$

Table 5.10: Example Scaling Factors for Hard Acceleration/Deceleration

Percent Hard Acceleration/ Deceleration	Pollutant				
	CO_2	VOC	NOx	CO	$PM_{2.5}$
0%	1	1	1	1	1
20%	1.338	0.837	1.150	0.859	1.219
40%	1.675	0.978	1.299	1.043	1.635
60%	2.013	1.421	1.449	1.551	2.249
80%	2.350	2.168	1.598	2.383	3.060
100%	2.688	3.218	1.748	3.541	4.069

5.4: Determining Performance Scores for Each Pollutant

The above four performance measures translate into scaling factors, which are applied to the base emission rates for the vehicle. The basic setup for this system is shown in Figure 5.3.

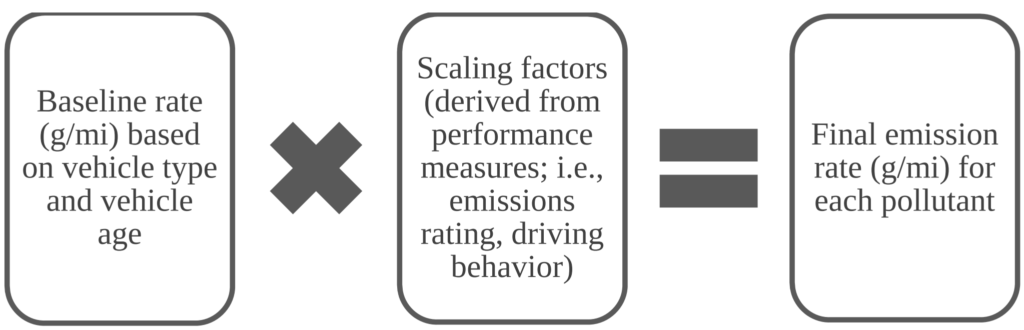

Figure 5.3: Basic method of determining pollutant rates.

Base emission rates are determined by vehicle class and model year. The final emission rate for each pollutant can be determined as (Equation 5.8):

$$New\ Rate\ \left(\frac{g}{mi}\right) = \ Base\ Rate\ \left(\frac{g}{mi}\right) \times ERF \times FEF \times AAF \times ((1 - HP) + HP \times HSF) \qquad 5.8$$

Where, ERF is the scaling factor based on emissions rating (Table 5.5), FEF is the scaling factor based on fuel efficiency (Equation 5.3), AAF is the scaling factor based on hard acceleration/ deceleration (from Table 5.10 equations), HP is the percentage of highway driving (speed over 50 mph), and HSF is the scaling factor from percent of highway speeds over 60 mph (from Table 5.8 equations). If the emissions rating factor or fuel efficiency factor do not apply to a particular pollutant, they are omitted from the equation.

Scaling factors based on EPA Air Pollution Score are only applicable to NOx, CO, and $PM_{2.5}$ emissions, while the scaling factor related to GHG Score is only applicable to CO_2 emissions. In addition, while hard acceleration and deceleration can occur at any time while driving, highway speeds over 60 mph would only occur during highway travel. Thus, performance on this measure should theoretically only affect the emission rates when traveling on a highway.

The final emission rates will be used to determine a final performance score for each pollutant. Scoring the performance requires comparing the individual's emission rate of each pollutant to the emission rates of all others within the same vehicle class. It was decided that scoring of passenger cars and passenger trucks would occur along the same scale in this research for simplification, as these vehicles have similar functions and drive cycles.

5.4.1: Distributions

The simplest method of determining the performance score would be to determine where an emission value lies between the maximum and minimum possible emissions values. However, the distributions of possible emissions values for each pollutant are not necessarily linear, which would be the simplest distribution to assume. The probable distribution of emission rates for each pollutant type needed to be determined. For this research, many possible pollutant emission rates were generated for a passenger car, combining each of the vehicle age categories, emissions ratings, fuel economies, and the scaling factors developed above for highway speeds and hard acceleration. For the highway scaling factors, highway speed percentages over 60 mph of 0%, 20%, 40%, 60%, 80%, and 100% were utilized. The same percentages were used to calculate the scaling factors based on hard acceleration. These possible rates were ordered from smallest to largest, and graphed along an x-axis representing performance scores from zero to 100, with 100 being the highest (worst) emission rates possible. Figure 5.4 shows the resulting distributions, with trend lines to illustrate the distribution shapes.

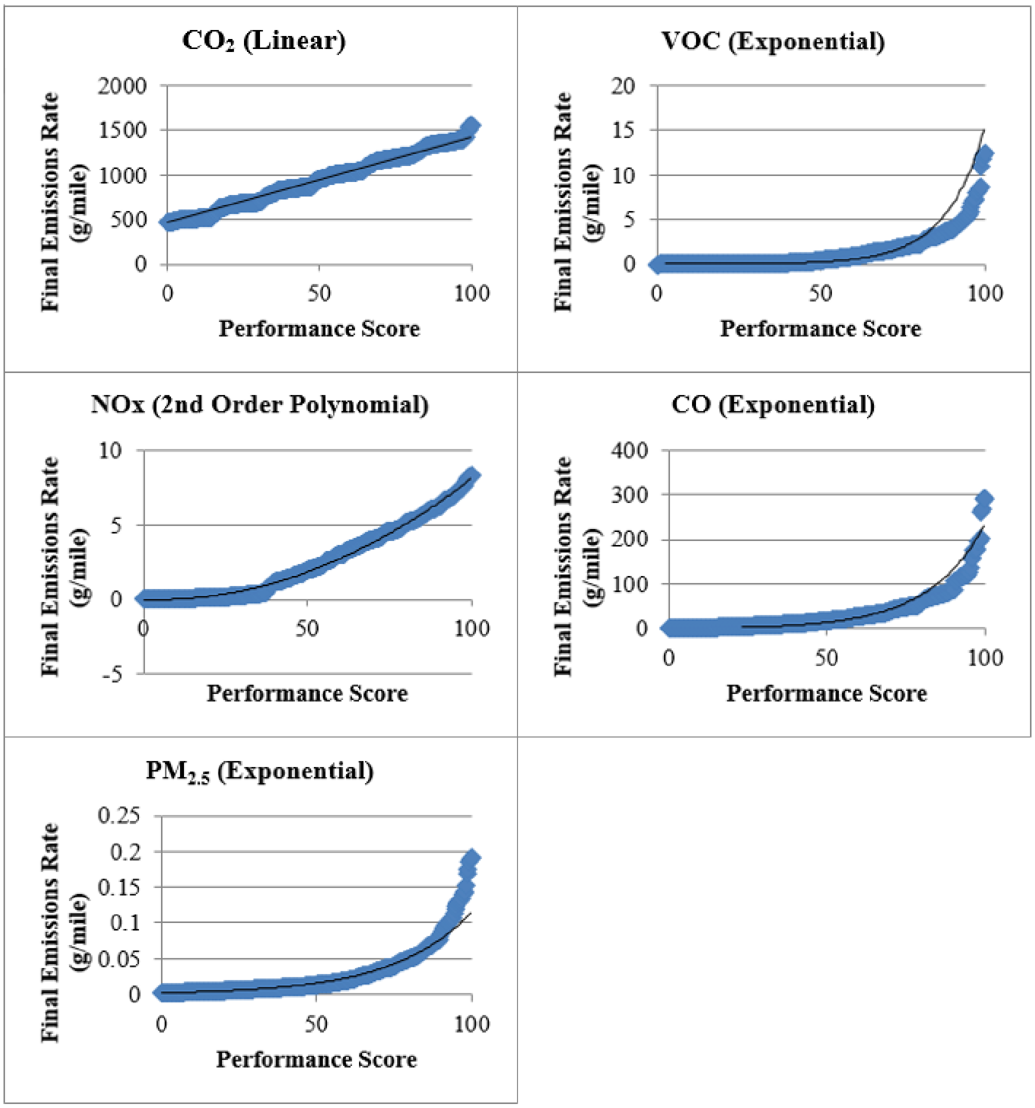

Figure 5.4: Distribution of possible emission rates and performance score values.

For the above examples, the highest emission rate would result from the highest possible base rate multiplied by scoring factors for 100 percent of highway speeds over 60 mph and 100 percent hard acceleration/deceleration. Of course, this worst-case is not likely in the real world. However, for the purposes of this research, the above distributions are assumed to be correct. It should also be noted that an equal probability was applied to all assumed combinations of scaling factors. Real-world data that would result from actual use of this system could be later substituted to better represent the actual distributions for each pollutant emission rate. Additionally, for this research we assume that the above distributions can be applied to passenger trucks as well. The chosen distribution type for each pollutant is summarized below in Table 5.11, along with the equations and R^2 values of the trend lines used to determine the distribution shape.

Table 5.11: Pollutant Distribution Shapes

Pollutant	Distribution	Equation	R-Squared Value
CO_2	Linear	$y = 9.6638x + 463.84$	$R^2 = 0.9897$
VOC	Exponential	$y = 0.0039e^{0.0828x}$	$R^2 = 0.9761$
NOx	2nd Order Polynomial	$y = 0.0009x^2 + 0.0074x$	$R^2 = 0.9939$
CO	Exponential	$y = 0.8774^{0.0558x}$	$R^2 = 0.9393$
$PM_{2.5}$	Exponential	$y = 0.0022e^{0.0397x}$	$R^2 = 0.9846$
Where y is the final emission rate for the pollutant and x is the performance score.			

These distributions are used to determine performance scores for each pollutant by determining what score from a scale of zero to 100 corresponds to the vehicle's emission rate. In other words, the above distribution types can be solved to determine the value on the 'x-axis.' Although emission rates for NOx, CO, and $PM_{2.5}$ can equal zero with a zero-emission vehicle, that minimum value is not used in calculation, as an exponential cannot equal zero. An emission rate of zero g/mi would automatically be assumed to score a performance of zero, with that as the best possible score.

In order to determine final performance score, the variables used in the above distributions must be determined. For a linear distribution, as used for CO_2, an individual's performance score would be determined as (Equation 5.9):

$$Performance\ Score\ for\ CO_2 = \frac{100 * (Individual's\ Final\ Emissions\ Rate_{CO_2} - Minimum\ Possible\ Rate_{CO_2})}{Maximum\ Emissions\ Rate_{CO_2} - Minimum\ Nonzero\ Emissions\ Rate_{CO_2}} \quad 5.9$$

For a 2nd order polynomial equation, as used for NOx, an individual's performance score would be calculated as (Equation 5.10):

$$Performance\ Score\ for\ NOx = 100 * \sqrt{\frac{Individual's\ Final\ Emissions\ Rate_{NOx} - Minimum\ Possible\ Rate_{NOx}}{Maximum\ Emissions\ Rate_{NOx} - Minimum\ Possible\ Rate_{NOx}}} \quad 5.10$$

For an exponential equation, as used for VOC, CO, and $PM_{2.5}$, an individual's performance score would be calculated as an exponential equation, based on the observed distribution shaped for these pollutants (Equation 5.11):

$$Performance\ Score\ for\ Pollutant\ i = \frac{100 * \ln(Individual's\ Final\ Emissions\ Rate_i / Minimum\ Nonzero\ Rate_i)}{\ln(Maximum\ Emissions\ Rate_i / Minimum\ Nonzero\ Emissions\ Rate_i)} \quad 5.11$$

With the above equations, a performance score can be calculated for each pollutant. If desired, passenger cars and passenger trucks could be grouped together for scoring, and both vehicle classes would be considered when determining the minimum and maximum possible emission rates.

5.4.2: Example Calculation

To illustrate all of the above concepts, the performance score for NOx is calculated based on the following inputs shown in Table 5.12.

Table 5.12: NOx Performance Score Example Data Inputs

Input	Assumption
Vehicle Type	Passenger Car
Vehicle Age	2005
Base NOx Emission Rate (g/mile)	0.140
Vehicle Emissions Rating	8
Scaling Factor Based on Emissions Rating (ERF)	0.214685
Percent Highway Travel (HP)	20%
Percent Highway Travel >60 mph	60%
Percent 'Hard' Acceleration/ Deceleration	40%

The scaling factor for based on percent of highway travel over 60 mph (HSF) is calculated using (Equation 5.12):

$$\mathit{Scaling\ Factor\ for\ Measure}\ 7_{NOx} = (-1.211 \times 0.60^2) + (1.9954 \times 0.60) + 1 = 1.761 \quad 5.12$$

The scaling factor based on percent hard acceleration/deceleration (AAF) is calculated as (Equation 5.13):

$$\mathit{Scaling\ Factor\ for\ Measure}\ 8_{NOx} = (0.7479 \times 0.40) + 1 = 1.299 \quad 5.13$$

The final emission rate for NOx in this example can be determined as (Equation 5.14):

$$\mathit{New\ Rate}\ \left(\frac{g}{mi}\right) = \mathit{Base\ Rate}\ \left(\frac{g}{mi}\right) \times ERF \times FEF \times AAF \times \left((1 - HP) + HP \times HSF\right) \quad 5.14$$

$$= 0.140\frac{g}{mi} \times 0.214685 \times 1 \times 1.299 \times (0.80 + 0.20 \times 1.761) = 0.045\frac{g}{mi}$$

The maximum possible emission rate for NOx for a passenger was 8.346 grams per mile based on the available MOVES data and the worst performance scenario. The minimum emission rate was zero for a vehicle with an emissions rating of 10. Thus, the performance score for NOx for this example would be calculated as (Equation 5.15):

$$\mathit{Performance\ Score\ for\ NOx} = 100 * \sqrt{\frac{0.045 - 0}{8.346 - 0}} = 7.3 \quad 5.15$$

5.4.3: Determining Final Performance Score

A final overall performance score can then be calculated based on performance for each pollutant. The final score for this research is still on a scale from zero to 100. Final performance could be a simple average of performance on each pollutant; however, a weighted average would be more applicable. The weighted average would be calculated as (Equation 5.16):

$$\mathit{Final\ Performance\ Score} = \sum_{i=1}^{5} \mathit{Score\ for\ Pollutant}\ i \times \mathit{Desired\ Weight\ for\ Pollutant}\ i \quad 5.16$$

The weights used should add up to one, or 100 percent. With five pollutants used in this framework, a basic average would be the same as using a weight of 0.2 for each pollutant. However, the advantage of a weighted average is that the final performance score can include greater consideration of pollutants deemed crucial or problematic. For example, NOx emissions are a problem in many Texas urban areas, so it may be desirable to assign greater weight to NOx performance. The weight values could be assigned by the agency using this framework, depending on what pollutants are of greater concern.

5.5: Concluding Remarks

Five of the performance measures are used to determine approximate emission rates for an individual vehicle, which can then be used to calculate a final performance score. The age of the vehicle (Measure 5) is used to identify the base emission rates for the vehicle. The rates may then be increased or decreased based on aggressive driving behaviors, including the amounts of highway speed over optimal air quality speed (Measure 7) and of the amount of hard acceleration/braking (Measure 8), the vehicle emissions rating (Measure 3) and fuel efficiency of the vehicle (Measure 4), where applicable. An individual has greater immediate control over driving behaviors, while vehicle ownership changes are made in the long-term.

The final emission rates for the individual vehicle are determined by scaling the base rates up and/or down based on performance measurement. A score between zero and 100 is given for each pollutant based on the final emission rates and the expected distribution of users across the system. Actual system data would be desirable to better determine the correct distributions for each pollutant. A final performance score is determined based on the score for each pollutant and the importance given to each pollutant. This final score is used in the next section to determine how to apply pricing to the individual.

6. USE OF MEASURES IN ESTABLISHING A MILEAGE-BASED USER FEE SYSTEM

6.1: Pricing System

Performance measurement, as discussed in the previous section, is used to determine a final performance score for an individual vehicle, which in turn will be used to determine what rate per mile the individual will pay. It is desirable to consider how the individual's performance compares to others in the system. The simplest method, which was used in this research, is to calculate the ratio of the individual's final performance score to the average performance score across the system for that vehicle class. This ratio can then be multiplied by a base mileage fee. Thus, if an individual performs better than average, they pay less; and if they perform worse than average, they pay more. Additionally, the base fee would likely vary by vehicle class. Since heavy-duty vehicles typically emit more than light-duty vehicles per mile, a higher base rate should apply.

Finally, since mileage occurring during certain times and places is of interest in the performance measurement framework, a higher fee may be charged per mile for mileage occurring in certain places or at certain times. Thus, increase factors could be applied, as determined by the agency, to the rate applied to those miles. For example, the agency could determine a certain percentage increase in mileage fee rates for all mileage driven during peak hours or for all mileage driven within the central business district. Mileage driven during specified times and within specified locations could have both increase factors applied to them. Therefore, for this research, this basic calculation for determining the fee per mile assessed to the user is used (Equation 6.1):

$$\begin{aligned} &\mathit{Final\ Fee\ for\ Mileage\ Within\ Specific\ Times\ or\ Locations}\left(\frac{\$}{mi}\right) \qquad 6.1 \\ &= \mathit{Base\ Fee\ for\ Vehicle\ Class}\left(\frac{\$}{mi}\right) \times \frac{\mathit{Individual\ Performance\ Score}}{\mathit{Average\ Score\ for\ Vehicle\ Class}} \\ &\times \mathit{Increase\ Factors\ for\ Time\ or\ Location} \end{aligned}$$

This simple method for calculating the user fee could easily be adapted or altered depending on the needs of the agency.

6.2: Feedback Loop

Since the goal of this pricing system is to lower emissions by changing driver behavior, it would be extremely important to assess whether or not emissions and behavior are actually changed by this pricing.

For this research, an elasticity value of -0.2 is assumed for mileage for all vehicle types. In other words, each 1 percent increase in price corresponds to a 0.2 percent decrease in mileage. Although there are other factors, it was assumed for this research that changes in mileage will directly correspond to changes in total pollutants emitted by each vehicle since emission rates are multiplied by mileage to determine total emissions. For example, a 5 percent decrease in mileage would result in a 5 percent decrease in total emissions. Using the above elasticity value, base mileage rates can be adjusted as (Equation 6.2):

$$New\ Base\ Rate\ \left(in\ \frac{¢}{mile}\right) = Initial\ Rate \times (1 - Desired\ Mileage\ Decrease\ \%)^{1/elasticity} \qquad 6.2$$

The actual changes in mileage in response to price changes could be tracked over time to help calibrate the actual elasticity in the real world. Price can continue to be adjusted until set air quality goals are reached. Figure 6.1 illustrates the basic feedback loop suggested for this research.

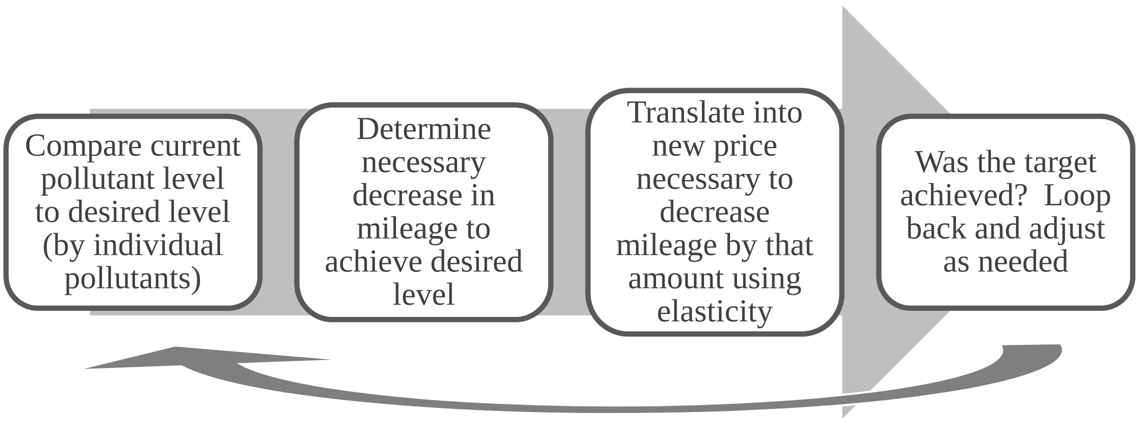

Figure 6.1: Illustration of feedback loop.

Of course, different drivers will respond differently to price changes, which emphasizes the need for ongoing adjustments. With real-world data, elasticity values could be updated as these behaviors are tracked over time. In addition, this pricing framework may encourage drivers to change their driving behaviors, including their highway speeds and aggressive driving behaviors. Changes to vehicle types would likely occur over a longer period of time as it is more difficult for most drivers to purchase a new vehicle.

6.3: Concluding Remarks

The mileage fee is intended to reduce pollutant levels by inducing a change in driver behavior, especially through a decrease in mileage. For this research, a fairly simple calculation for the fee charged to an individual is suggested; however, different functions could be used. For example, a calculated cost of damage to health and the environment could be used in order that drivers may pay for the external cost they impose. Additionally, different base rates could be set for different vehicle classes based on relative emission levels.

The use of elasticity is suggested to determine necessary fee increases required to decrease mileage by a certain amount. The entire process of performance measurement and pricing is illustrated through example calculations in the next section using real-world travel data.

7. EXAMPLE APPLICATION OF SYSTEM

7.1: Overview

Actual travel data from two different vehicles was used in this example to illustrate how the performance measurement and pricing frameworks could be applied. Due to confidentially, several assumptions are made, including:

- Vehicle characteristics of age, emissions rating, and fuel efficiency;
- Facilities/times of interest to charge at a higher mileage fee;
- Importance factors applied to each pollutant type to calculate a final aggregated performance score;
- Increase of base mileage fee on certain facilities and during specific times; and
- Desired mileage decrease over time.

In addition, the performance measures for trips on transit and driver training were not evaluated in this example. As these performance measures have a more indirect effect on per mile emissions, they would not tie directly into the mileage fee. The recommended application for these measures would be to provide some sort of waiver or reduction on the final cost owed by the user if driver training or transit were utilized.

7.2: Description of Data Set

The data used in this example were collected by GPS units installed in private vehicles. The GPS data were collected for a project conducted by the Texas A&M Transportation Institute. Data from a passenger car and from a passenger truck are used in this example. Both vehicles were owned and driven by TTI employees; however, specific vehicle information was not provided due to confidentiality. Mileage occurred in and around Austin, Texas. Data collected for the passenger car occurred between March 19, 2011, and March 31, 2011. For the passenger truck, data was collected between March 1, 2011, and April 1, 2011. A computer program called QSports was used to download the data. QSports also includes mapping, so that the vehicle routes could be observed. Figure 7.1 illustrates where all travel occurred for the passenger car between

March 19 and March 31. Similarly, Figure 7.2 shows all observed travel made by the passenger truck.

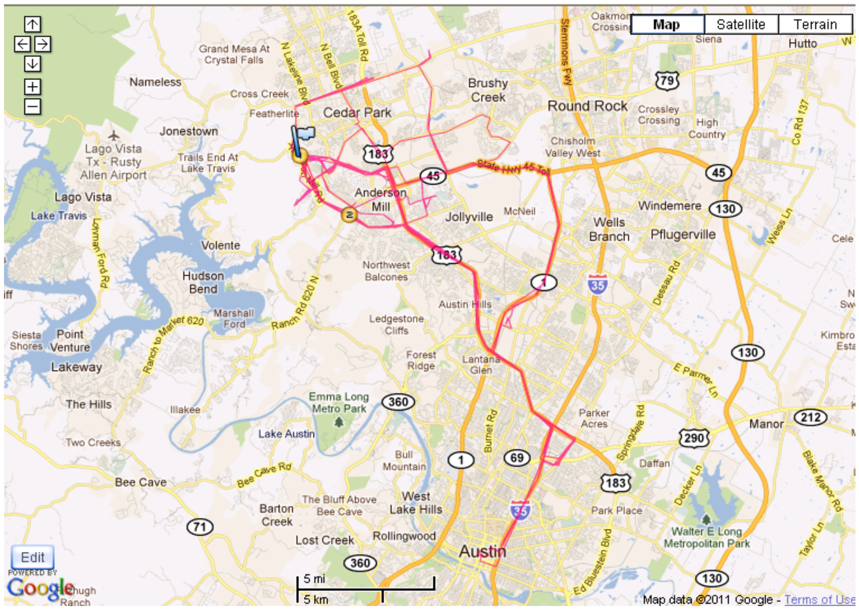

Figure 7.1: Passenger car routes (created utilizing *72*).

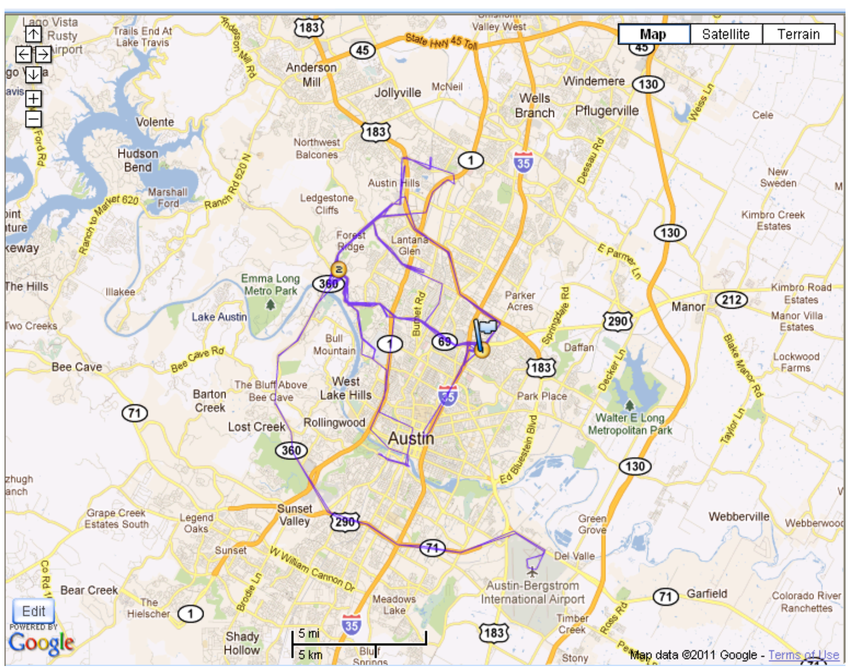

Figure 7.2: Passenger truck routes (created utilizing *72*).

Data, including time of day and speed data, were exported to Microsoft Excel for analysis. Acceleration data were calculated using the second-by-second speed data as in Equation 7.1:

$$Acceleration = \frac{Speed_2 - Speed_1}{Time_2 - Time_1} \quad 7.1$$

In other words, second-by-second acceleration is just the difference between the previous speed and the current speed. If the current speed is lower than the previous speed, the vehicle has decelerated. To calculate the percent of 'hard' acceleration and deceleration, Equation 4.3 was utilized. As an example, the acceleration/deceleration data for the study vehicles is summarized in Table 7.1, along with the calculated percent of hard acceleration/deceleration.

Table 7.1: Acceleration and Deceleration Data Summary

Criteria		**Time Meeting Threshold (seconds)**	
		Passenger Car	**Passenger Truck**
Total Travel Time		75,131	60,677
For Speed Less Than 25 mph	Acceleration >= 3.5 mph/sec	1,136	820
	Deceleration <= -3.5 mph/sec	1,323	1,326
For Speed Between 25 and 50 mph	Acceleration >= 2 mph/sec	1,259	1,434
	Deceleration <= -2 mph/sec	1,094	1,238
For Speed Greater than or Equal to 50 mph	Acceleration >= 1 mph/sec	542	566
	Deceleration <= -1 mph/sec	570	491
Total Hard Acceleration/Deceleration Time		5,924	5,875
Percent Hard Acceleration/Deceleration		5,924/75,131= 7.88%	5,875/60,677= 9.68%

It was assumed that peak hour travel was of particular interest for pricing. The mileage occurring during peak hours was estimated from the data. Distance traveled each second was calculated as (Equation 7.2):

$$Distance\ (miles) = Speed\ (mph) \times \frac{1\ hour}{3600\ seconds} \times Time\ difference\ (seconds) \quad 7.2$$

Distance traveled during peak hours were aggregated to obtain total mileage occurring during peak hours. Morning peak hours were assumed to be between 7:00 A.M. and

9:00 A.M. and evening peak hours were assumed to be between 4:00 P.M. and 6:00 P.M. As an illustration, it was assumed that mileage traveled on Interstate Highway 35 (IH-35) and on Mopac Expressway was of particular interest for pricing.

All the data were analyzed to obtain the statistics necessary for evaluating performance. The results are summarized in Table 7.2 below.

Table 7.2: Overview Statistics of Example GPS Data

Statistic	Passenger Car	Passenger Truck
Total Travel Time	20.87 hours	16.85 hours
Percent Highway Travel	12.88%	10.77%
Percent Highway Travel >60 mph	63.82%	43.27%
Percent 'Hard' Acceleration/ Deceleration	7.88%	9.68%
Total Mileage	443.85 miles	343.31 miles
Time Traveled during Peak Hours	5.67 hours	7.80 hours
Total Mileage during Peak Hours	100.32 miles	172.07 miles
Total Mopac and IH-35 Miles	40.7 miles	11.1 miles
Mopac/IH-35 Miles during Peak Hours	8.9 miles	5.2 miles

The performance measures involving mileage are shown in Table 7.2, with mileage during peak hours and on the specified facilities differentiated for Measure 2, Vehicle-Miles Traveled in Certain Locations and At Certain Times.

Finally, specific information on the model and age of the vehicles observed was not provided due to confidentiality. For illustration purposes, the passenger car was assumed to be a 2007 Ford Focus. Using the EPA Green Vehicle Guide, this car would have an EPA air pollution score of 7 and an average fuel efficiency of 26 miles per gallon of gasoline. The passenger truck was assumed to be a 2007 two-door Chevrolet Silverado, which has an EPA air pollution score of 2 and an average fuel efficiency of 16 miles per gallon of gasoline. This model year was selected as it is the first year with online EPA air pollution score data for passenger trucks.

7.3: Performance Measurement Quantification and Determination of Final Performance Score

The above information, whether assumed or obtained from data analysis, is used to determine scaling factors that are applied to base emission rates. Vehicle class and vehicle age (Measure 5) affect the base emission rates. Performance on the following measures is used to determine how much higher or lower an individual's emission rates are from the base emission rates:

- Measure 3 – Vehicle Emissions Rating;
- Measure 4 – Vehicle Fuel Economy;
- Measure 7 – Time Traveled at Greater Than Optimal Air Quality Speed; and
- Measure 8 – Time Spent Aggressively Accelerating/Braking.

7.3.1: Passenger Car

The first performance measure was total mileage traveled during the time period. This was 443.85 miles for the passenger car. Table 7.3 illustrates Measure 2, which includes the allocation of mileage based on time and location.

Table 7.3: Passenger Car Mileage Allocation

Area	Time of Day		Area Total
	Peak	Off-Peak	
IH-35 and Mopac	8.9	31.8	40.7
All other areas	91.42	311.73	403.15
Time of Day Total	100.32	343.53	**443.85**

Vehicle class (passenger car) and vehicle model year (2007) were used to determine base emission rates for the vehicle, which are:

- 470.543 grams per mile of CO_2;
- 0.0063 grams per mile of VOC;
- 0.0530 grams per mile of NO_x;
- 1.2437 grams per mile of CO; and
- 0.0024 grams per mile of $PM_{2.5}$.

Performance on other measures affects the factors used to scale base emission rates up or down. The individual's performance and resulting scaling factors are illustrated below in Table 7.4. Scaling factors for Measure 3 (emissions rating) and Measure 4 (fuel efficiency) were determined using the values in Table 5.5 and Table 5.8, respectively. Scaling factors for Measure 7 (highway speed over 60 mph) and Measure 8 (time spent aggressively accelerating/braking) were determined using the equations identified in Table 5.9 and Table 5.11, respectively. For example, the scaling factor for NOx for Measure 7 was calculated using (Equation 7.3):

$$Scaling\ Factor\ for\ Measure\ 7_{NOx} = (-1.211 \times 0.6382^2) + (1.995 \times 0.6382) + 1 = 1.7802 \qquad 7.3$$

Table 7.4: Passenger Car Performance and Scaling Factors

Performance on Measures:		**Emissions Effect: Scaling Factors**					
		Symbol	**CO_2**	**VOC**	**NOx**	**CO**	**$PM_{2.5}$**
3 - Air Pollution Score	6	ERF	-	-	0.7543	1	1
4 - Fuel Efficiency	26	FEF	0.7283	-	-	-	-
7 - Percent Highway Speed above 60 mph	63.82%	HSF	1.0930	2.2924	1.7802	2.5065	1.2620
8 - Percent Hard Acceleration/ Deceleration	7.88%	AAF	1.1330	0.8997	1.0589	0.9089	1.0627

Approximately 12.88 percent of the travel occurred at or above 50 mph, which affects the extent to which the scaling factor from the highway speed measure affects the emission rates. Highway travel was assumed to occur for all speeds 50 mph and greater, in order to illustrate the methodology described in previous sections, which could be used as a generalization when location data is not available. It should be noted that based on location data approximately eight percent of travel at speeds over 50 mph occurred on non-freeway facilities, primarily on a high-speed farm-to-market road.

Scaling factors are applied to the individual's base emission rates to obtain final emission rates as previously shown in Equation 5.6:

$$New\ Rate\ \left(\frac{g}{mi}\right) = Base\ Rate\ \left(\frac{g}{mi}\right) \times ERF \times FEF \times AAF \times ((1 - HP) + HP \times HSF) \qquad 5.6$$

Where, ERF is the scaling factor based on emissions rating, FEF is the scaling factor based on fuel efficiency, AAF is the scaling factor based on aggressive acceleration or deceleration, HP is the percentage of highway driving (speed over 50 mph), and HSF is the scaling factor from percent of highway speeds over 60 mph. If the emissions rating factor or fuel efficiency factor do not apply to a particular pollutant, they are omitted from the equation. As an example, the new emissions rate for CO_2 was calculated as (Equation 7.4):

$$New\ Rate_{CO_2} = \left(470.543\frac{g}{mi}\right) \times 0.7283 \times 1.1330 \times \left(0.8712 + (0.1288 \times 1.0930)\right)$$
$$= 392.926\frac{g}{mi} \qquad 7.4$$

Based on minimum and maximum possible emission rates for similar vehicle types, the performance score out of 100 for each pollutant was calculated using Equations 5.6 and 5.7. The maximum and minimum possible emission rates for the passenger car are shown in Table 7.5.

Table 7.5: Maximum and Minimum Emission Rates for Passenger Cars

Values for Group of Passenger Cars	Pollutant				
	CO_2	VOC	NOx	CO	$PM_{2.5}$
Maximum Possible Emission Rates	1510.356	16.9188	8.1779	266.3299	0.1680
Minimum Possible Non-Zero Emission Rates	187.012	0.0033	0.0199	0.7527	0.0019

The provided base emission rates and the calculated new emission rates for each pollutant are shown in Table 7.6, along with the performance score for each pollutant. The final performance score is aggregated from the performance score on each pollutant, based on assumed importance weights applied to each pollutant. This allows some pollutants to be given more consideration if desired.

As an illustration of how this might occur, the relative cost of each pollutant type was calculated for Texas in 2011. The total emissions from on-road sources in Texas was obtained from the EPA 2011 National Emissions Inventory (NEI) Data available online (*73*). An average cost per ton for each pollutant (in 1992 dollars) was estimated by H.S. Matthews, et al. based on calculated external costs of various pollutants in different studies (*74*). The average external cost per ton for each pollutant was converted to 2011 dollars and was multiplied by the total 2011 Texas on-road emissions to determine a total cost for comparison between pollutants. The results are shown in Table 7.7 along with the relative percentage cost of each pollutant. These percentages were utilized to weight each pollutant for calculation of the final performance score. The final performance score for the passenger car is also shown in Table 7.6.

Table 7.6: Passenger Car Performance Scores

	Pollutant				
	CO_2	**VOC**	**NOx**	**CO**	**$PM_{2.5}$**
Base Rate in g/mi	470.543	0.0063	0.0530	1.2437	0.0024
New Rate in g/mi	392.926	0.0066	0.0466	1.3497	0.0026
Performance Score (out of 100)	**15.560**	**8.135**	**5.719**	**9.951**	**7.309**
Assumed Pollutant Importance Weight	39.95%	6.45%	27.18%	22.49%	3.93%
Final Performance Score (out of 100)	**10.821**				

Table 7.7: Estimated 2011 Cost and Relative Importance of Each Pollutant Type in Texas

Pollutant	**2011 On-Road Emissions in Texas in tons (*72*)**	**1992 Average External Cost per ton (*73*)**	**Estimated 2011 Average External Cost per ton**	**Estimated 2011 On-Road Pollutant Cost**	**Percent of Total Cost**
CO_2	150,442,350.24	$13/ton	$20.83/ton	$3,133,366,202.48	39.95%
VOC	197,403.99	$1,600/ton	$2,563.41/ton	$ 506,026,889.94	6.45%
NOx	475,229.03	$2,800/ton	$4,485.96/ton	$2,131,860,007.20	27.18%
CO	2,117,208.82	$520/ton	$833.11/ton	$1,763,862,515.37	22.49%
PM	44,778.03	$4,300/ton	$6,889.16/ton	$ 308,482,915.81	3.93%
			Total	**$ 7,843,598,530.81**	**100.00%**

As stated previously, additional real-world data that would result from actual use of this system could be later substituted to better represent the actual distributions for each pollutant emission rate when determining performance scores for each pollutant. Actual real-world data obtained through use of the system would better represent the vehicle fleet and how actual drivers behave.

7.3.2: Passenger Truck

The first performance measure was total mileage traveled during the time period (Table 7.8).

Table 7.8: Passenger Truck Mileage Allocation

Area	Time of Day		Area Total
	Peak	Off-Peak	
IH-35 and Mopac	5.2	5.9	11.1
All other areas	166.87	165.34	332.21
Time of Day Total	172.07	171.24	**343.31**

Next, vehicle class (passenger truck) and vehicle model year (2007) were used to determine base emission rates for the vehicle, which are:

- 630.073 grams per mile of CO_2;
- 0.0263 grams per mile of VOC;
- 0.2025 grams per mile of NOx;
- 1.8140 grams per mile of CO; and
- 0.0031 grams per mile of $PM_{2.5}$.

The passenger truck had higher emission rates than the passenger car, despite being in the same age category which is expected due to differences between the two vehicle classes. Performance on other measures affects the factors used to scale base emission rates up or down. The individual's performance and resulting scaling factors are illustrated below in Table 7.9.

Table 7.9: Passenger Truck Performance and Scaling Factors

Performance on Measures:		Emissions Effect: Scaling Factors					
		Symbol	**CO_2**	**VOC**	**NOx**	**CO**	**$PM_{2.5}$**
3 - Air Pollution Score	2	ERF	-	-	1	1	1
4 - Fuel Efficiency	16	FEF	0.884	-	-	-	-
7 - Percent Highway Speed above 60 mph	43.27%	HSF	1.0953	1.7781	1.1046	1.5313	1.2262
8 - Percent Hard Acceleration/ Deceleration	9.68%	AAF	1.1422	1.1886	1.1718	0.9259	0.9719

As shown, the scaling factors for Measure 3 (emissions rating) and Measure 4 (fuel efficiency) are all one. In other words, based on the model year, the fuel efficiency, and the EPA Air Pollution Score, no improvements to the base emission rates could be assumed. The base emission rates are less than the maximum allowed rates based on Federal Tier 2 standards.

Additionally, 10.77 percent of the travel occurred above highway speeds, which affects how much the scaling factors from the highway speed measure contribute to the calculated new emission rates.

The maximum and minimum possible emission rates for the passenger truck are shown in Table 7.10.

Table 7.10: Maximum and Minimum Emission Rates for Passenger Trucks

Values for Group of Passenger Trucks	Pollutant				
	CO_2	**VOC**	**NOx**	**CO**	**$PM_{2.5}$**
Maximum Possible Emission Rates	1941.644	29.5646	6.8763	241.7037	0.3339
Minimum Possible Non-Zero Emission Rates	186.991	0.0240	0.0200	1.2642	0.0029

The provided base emission rates and the calculated new emission rates for each pollutant are shown in Table 7.11, along with the performance score for each pollutant and the calculated final performance score.

Table 7.11: Passenger Truck Performance Scores

	Pollutant				
	CO_2	**VOC**	**NOx**	**CO**	**$PM_{2.5}$**
Base Rate in g/mi	630.073	0.0263	0.2025	1.8140	0.0031
New Rate in g/mi	642.717	0.0339	0.2400	1.7757	0.0031
Performance Score (out of 100)	**25.972**	**4.845**	**17.911**	**6.467**	**1.312**
Assumed Pollutant Importance Weight	39.95%	6.45%	27.18%	22.49%	3.93%
Final Performance Score (out of 100)	**17.063**				

The final calculated performance scores for both the passenger car and the passenger truck are now used to determine pricing.

7.4: Application of Mileage-Based User Fee

It is desirable to compare individual performance to system average performance, so that if the individual performs better than average they will be charged less than average, and if the individual performs worse than average they will be charged more. An average final performance score of 37.206 and 37.868 was calculated for use as the system average for passenger cars and passenger trucks, respectively, in this example. The average light-duty vehicle age in 2011 was 10.9 years old, which was assumed to be a model year 2000 vehicle (*75*). For that model year, an air pollution score of 1 was assumed, based on Table 4.2. In 2011, the fleet average fuel economy was approximately 23.2 miles per gallon for light-duty vehicles (*75*). Average percent highway driving (34.38%), average percent of highway speeds over 60 mph (55.90%), and average percent hard acceleration/deceleration (38.98%) was calculated from the speed profiles used in Section 4 (Table 4.3 and Table 4.5). The calculations for final performance score for an average passenger car and for an average passenger truck are shown in Table 7.12 and Table 7.13, respectively.

Table 7.12: Average Passenger Car Performance Calculation

Performance on Measures:		Emissions Effect: Scaling Factors					
		Symbol	**CO_2**	**VOC**	**NOx**	**CO**	**$PM_{2.5}$**
3 - Air Pollution Score	1	ERF	-	-	1	1	1
4 - Fuel Efficiency	23.2	FEF	0.807	-	-	-	-
7 - Percent Highway Speed above 60 mph	55.90%	HSF	1.0919	2.2348	1.7370	2.4517	1.2654
8 - Percent Hard Acceleration/ Deceleration	38.98%	AAF	1.6580	1.5146	1.2915	1.0254	1.6092
Base Emission Rate in g/mi			476.155	0.093	0.678	4.902	0.004
New Emission Rate in g/mi			656.876	0.2007	1.0975	7.5353	0.0070
Performance Score (out of 100)			**35.506**	**47.999**	**36.645**	**39.253**	**28.949**
Final Performance Score (out of 100)		**37.206**					

Table 7.13: Average Passenger Truck Performance Calculation

Performance on Measures:		Emissions Effect: Scaling Factors					
		Symbol	**CO_2**	**VOC**	**NOx**	**CO**	**$PM_{2.5}$**
3 - Air Pollution Score	1	ERF	-	-	1	1	1
4 - Fuel Efficiency	23.2	FEF	0.579	-	-	-	-
7 - Percent Highway Speed above 60 mph	55.90%	HSF	1.1097	1.9020	1.1351	1.5912	1.2540
8 - Percent Hard Acceleration/ Deceleration	38.98%	AAF	1.5726	1.9895	1.4938	1.0227	1.3762
Base Emission Rate in g/mi			663.515	0.251	1.32	8.892	0.005
New Emission Rate in g/mi			626.738	0.6542	2.0635	10.9421	0.0075
Performance Score (out of 100)			**25.062**	**46.449**	**54.594**	**41.082**	**19.894**
Final Performance Score (out of 100)		**37.868**					

A base mileage fee of $0.02 per mile for light-duty vehicles was assumed based on the literature review and the approximate value of state and federal fuel taxes in Texas.

Although many functions could be used to calculate how performance affects the mileage fee charged to the individual, this example assumes the simple equation presented in the previous section (Equation 6.1). The passenger car performs better than the assumed system average, with a final performance score of 10.821. Therefore, the new rate assessed to this individual is 0.582 cents per mile rather than two cents, as shown in Equation 7.5:

$$Final\ Mileage\ Fee\ for\ Passenger\ Car \tag{7.5}$$
$$= Base\ Fee\ for\ Vehicle\ Class\ \left(\frac{cents}{mile}\right) \times \frac{Individual\ Performance\ Score}{Average\ Score\ for\ Vehicle\ Class} = \frac{2\ cents}{mile} \times \frac{10.821}{37.206} = 0.582\ cents\ per\ mile$$

The passenger truck also performs better than the assumed average with a final score of 17.063, so will be charged at 0.901 cents per mile, as shown in Equation 7.6:

$$Final\ Mileage\ Fee\ for\ Passenger\ Truck \tag{7.6}$$
$$= Base\ Fee\ for\ Vehicle\ Class\ \left(\frac{cents}{mile}\right) \times \frac{Individual\ Performance\ Score}{Average\ Score\ for\ Vehicle\ Class} = \frac{2\ cents}{mile} \times \frac{17.063}{37.868} = 0.901\ cents\ per\ mile$$

In addition, for this example mileage that occurs during peak hours and on certain facilities should be charged at a higher rate. IH-35 and Mopac were selected as facilities of interest for this example. We assume an increase factor of 2 for mileage that occurs during peak hours, as an example. This increase factor was based on variable congestion pricing in Stockholm, which ranged from 1 euro to 2 euros depending on time of day (*76*). An increase factor of 1.5 was selected for mileage occurring on IH-35 and Mopac. If mileage occurs on these facilities and during peak hours, both factors would apply, so the mileage fee would increase by 3 times the original amount. The final rates applied to mileage for the two vehicle types are shown in Table 7.14.

Table 7.14: Final Mileage Fees

Mileage Type	**Fee (cents/mile)**	
	Passenger Car	**Passenger Truck**
Mileage on IH-35 and Mopac during Peak Hours	1.745	2.704
Peak-Hour Mileage Off Facility	1.163	1.802
Mileage on IH-35 and Mopac during Off-Peak Hours	0.873	1.352
Non-Peak and Off Facility Mileage	0.582	0.901

Based on the mileage given above for each vehicle type, the total amount paid is shown in Table 7.15.

Table 7.15: Final Charge Assessed to User

Mileage Type	Passenger Car	Passenger Truck
Mileage on IH-35 and Mopac during Peak Hours	$0.16	$0.14
Peak-Hour Mileage Off Facility	$1.06	$3.01
Mileage on IH-35 and Mopac during Off-Peak Hours	$0.28	$0.08
Non-Peak and Non-Facility Mileage	$1.81	$1.49
Total	**$3.31**	**$4.72**

In the above example, the passenger car pays a similar amount to the passenger truck. The passenger car traveled more miles overall, but the passenger truck traveled more miles during peak hours and had a slightly higher charge per mile, based on performance on vehicle and driving behavior measures. Based on the assumed vehicle fuel efficiencies, the passenger car and passenger truck would have paid approximately $6.56 and $8.25, respectively, in federal and state fuel taxes for the mileage driven. Therefore, the amount paid using the mileage pricing framework and a base mileage fee of two cents per mile would be approximately one half of the amount paid in fuel taxes for both example vehicles. It makes sense that the amount paid would be less, as the overall performance scores of the two example vehicles were approximately one third to one half of the score for the average vehicle.

However, the purpose of this mileage fee is not to replace the income generated by the fuel tax, but to influence driver behavior to improve air quality. In addition, vehicle characteristics and driving behavior have a more significant impact on the amount paid in mileage fees than they do for the amount paid in fuel taxes, which is the purpose of this pricing framework.

7.5: Change in Travel

For the initial price, we assume the average cost per mile of owning and operating a vehicle in 2011 was 59.6 cents per mile (*75*). Much of that is a fixed cost, with approximately 19.7 cents per mile as a variable costs, or approximately 17.7 cents per mile without the fuel tax. With the initial base rate per mile of two cents per mile, the average cost per mile would be 19.7 cents per mile.

It is assumed that an agency has a goal to reduce emissions by two percent. The most direct way to reduce overall emissions is to reduce overall mileage. A new base fee needs to be determined to attempt to decrease mileage by 2 percent. The assumed elasticity between price and mileage is -0.2. The new required cost per mile of owning and operating a vehicle is calculated as (Equation 7.7):

$$New\ Price\ (P_2) = P_1 \times \left({}^{Q_2}\!/_{Q_1}\right)^{1/\eta} = \$0.197 \times (1 - .02)^{1/-.2} = \$0.218 \qquad 7.7$$

The new cost per mile required to reduce mileage by 2 percent is 21.8 cents per mile, an increase of 2.1 cents per mile. Therefore, the new mileage fee assessed to the user is 4.1 cents per mile.

The two individual vehicles utilized in this example are assumed to have the same performance on each performance measure as before, although in reality individuals would likely try to improve their performance over time to reduce their cost. The exception would be mileage driven, as the two individuals would decrease their mileage by 2 percent in response to the price increase. In that case, the new mileage fees and total charges paid by the two individuals are shown in Table 7.16, approximately twice the initial fees shown in Table 7.15, and slightly more than the fuel tax that would have been paid for the same mileage. The data utilized in this example was collected over approximately three weeks. Thus, the example fee assessed would still be a relatively low cost compared to other costs of transportation, including fixed costs.

Table 7.16: New Mileage Fees and Charges Assessed to User

Mileage Type	Passenger Car	Passenger Truck
Previous Mileage		
Mileage on IH-35 and Mopac during Peak Hours	8.9 miles	5.2 miles
Peak-Hour Mileage Off Facility	91.42 miles	166.87 miles
Mileage on IH-35 and Mopac during Off-Peak Hours	31.8 miles	5.9 miles
Non-Peak and Off Facility Mileage	311.73 miles	165.34 miles
New Mileage		
Mileage on IH-35 and Mopac during Peak Hours	8.72 miles	5.10 miles
Peak-Hour Mileage Off Facility	89.59 miles	163.53 miles
Mileage on IH-35 and Mopac during Off-Peak Hours	31.16 miles	5.78 miles
Non-Peak and Off Facility Mileage	305.50 miles	162.03 miles
New Mileage Fee (cents/mile)		
Mileage on IH-35 and Mopac during Peak Hours	3.577	5.542
Peak-Hour Mileage Off Facility	2.385	3.695
Mileage on IH-35 and Mopac during Off-Peak Hours	1.789	2.771
Non-Peak and Off Facility Mileage	1.192	1.847
New Charges Assed to User		
Mileage on IH-35 and Mopac during Peak Hours	$0.31	$0.28
Peak-Hour Mileage Off Facility	$2.14	$6.04
Mileage on IH-35 and Mopac during Off-Peak Hours	$0.56	$0.16
Non-Peak and Off Facility Mileage	$3.64	$2.99
Total	**$6.65**	**$9.48**

To illustrate the potential changes in overall emissions for the two vehicles, the calculated emissions rates for each vehicle are multiplied by the old mileage and the new mileage, as shown in Table 7.17.

Table 7.17: Change in Overall Emissions from Mileage Change

Vehicle	Scenario	Pollutants Emitted				
		CO_2 (kg)	VOC (g)	NOx (g)	CO (g)	$PM_{2.5}$ (g)
Passenger Car	Previous Mileage (443.85 miles)	174.400	2.935	20.677	599.081	1.170
	New Mileage (434.97 miles)	170.912	2.876	20.264	587.100	1.147
	Percent Change	-2%	-2%	-2%	-2%	-2%
Passenger Truck	Previous Mileage (343.31 miles)	220.651	11.631	82.382	609.612	1.060
	New Mileage (336.44 miles)	216.236	11.399	80.733	597.413	1.038
	Percent Change	-2%	-2%	-2%	-2%	-2%

As shown, the total pollutants emitted also decreased by two percent with the two percent mileage decrease due to the direct relationship between emissions and mileage. However, the actual emissions would likely decrease by more than two percent as road users adjust their driving behaviors and eventually replace their vehicles with newer models.

It should be noted that the elasticity is a theoretical value averaged over all users. The actual response to changes in price would be expected to vary significantly by individual, due to differences including demographics, income levels, and trip purposes (*77*). An individual's response tends to be in proportion to their perception of the impact of the price change on themselves, with the largest response typically coming from those impacted the most by a change in price. For example, a rural user who travels great distances may notice the impact of a price increase more than an urban driver, and may be more motivated to attempt to reduce trip lengths. A roadway user with a higher income level may not be as influenced by a price increase as a lower-income driver, and may make less effort to change driving behavior. Someone who drives primarily between work and home may not be able to reduce their mileage as someone who makes more non-work trips. Finally, changes in travel in response to a price increase tend to vary over the short-term versus the long-term, with studies showing that long-run elasticities are typically twice as large as short-run elasticities (*77*). In other words, a greater change in travel would be expected in the long-term.

With a real system in place, the actual response to changes in fees could be determined, and fees could then be adjusted accordingly. Eventually, an optimal price could be reached. However, consideration should be given to equity for lower-income travelers as the base mileage fee increases.

7.6: Potential Impacts and Policy Discussion

In the above examples, an increase in base price per mile was assumed to reduce the number of miles traveled. Certainly over time such a pricing framework has the potential to reduce miles traveled, as the total fee is directly related to miles traveled. Unlike the fuel tax, which is also affected by distance traveled, a fee assessed separately would be more visible to the roadway user and may be more likely to affect behavior than an increase in fuel tax. On a short-term basis, the roadway user may decrease the number of trips taken, particularly non-work trips. On a long-term basis, roadways users may attempt to live closer to employment areas, carpool, or make use of alternative modes of transportation, which would address Objective 6 (increase transit use) of this framework. Policy makers may need to increase transit capacity and areas of service. Road users may also begin avoiding higher-priced facilities or times-of-day if they are able. Using the framework in this research, significant increase in mileage-fees could be applied to specific areas or times, if desired by the agency. Employers may be encouraged to increase telecommuting and shifts in work hours to allow employees the flexibility to travel during off-peak times.

The age and type of vehicle driven also has a significant impact on pollutant emissions and affects the fee assessed to the user as well. However, most users would not be able to improve vehicle characteristics in the short-term due to the cost of purchasing a vehicle. To help achieve air quality goals, state governments could consider implementation of a program similar to the federal Car Allowance Rebate System, which provided incentives for citizens to purchase newer and more fuel-efficient vehicles in 2009. On average, fuel economy was improved by 58% between the vehicle traded in and the new vehicle with this program (*78*). Nearly 700,000 cars were purchased with this program, but funding was fully utilized in one month. More stringent requirements could be applied to increase the effectiveness of such a program, including requiring very high-efficiency and low pollutant vehicles to be purchased. Long-term, citizens are likely to purchase newer and lower-emitting vehicles on their own, especially if mileage pricing provides an increased incentive. As the vehicle fleet includes newer and newer vehicles, overall fuel efficiency and pollutant emissions improve, with this MBUF policy speeding up this change.

Road users would also be able to reduce the price paid per mile with changes in driving behavior; however, these changes may be more difficult for the average user to understand than reductions in mileage or improvement in vehicle characteristics. If aggressive driving performance measures are included in a pricing framework, public education would likely be necessary to communicate how drivers can improve their behavior. In addition, while 60 mph is considered an optimal speed in terms of air quality, many highways throughout the state of Texas have speed limits greater than 60 mph. If policy makers wish to include speed performance in a pricing framework, speed limits may need to be reduced or the performance measure could be assessed for travel above the speed limit instead. Encouraging drivers to travel well below the speed limit could present a safety concern.

Public outreach efforts would be a large part of any mileage based fee program in general. Road users are not likely to be aware of how much they currently pay in existing fuel taxes, as the amount is included in the total gas price. Many would likely react negatively to receiving a charge per mile driven and to potentially being charged higher based on performance measures. Education efforts could be vital in communicating how road users can decrease the amount they pay. As shown in the pricing example, users have the potential to pay less than the current fuel tax. Implementation of a pilot program would be especially useful. Through a pilot program, an agency could demonstrate to road users how a mileage-based fee system would work, identify and solve potential problems before implementation, and collect extensive real-world data for use in calibrating performance scoring.

Consideration of equity concerns would be important, especially if the desired base mileage fee is higher than the current fuel tax per mile. Mileage charges are likely to have a disproportionately negative impact on low-income drivers (*79*). Lower-income roadway users may be more constrained in terms of time-of-day travel and ability to reduce mileage through telecommuting. Similarly, lower-income users may have more difficulty relocating to reduce trip distance. Rural residents especially may drive much longer distances. Lower-income roadway users are more likely to own older and less fuel efficient vehicles. Obtaining a better-performing vehicle would be a more significant burden on lower income drivers. On the other hand, it should be noted that lower income drivers would likely already be paying a higher fuel tax per mile, and switching to a mileage-based fee may not cause an undue burden. In addition, they may already avoid certain facilities such as toll roads and may drive fewer miles. Use of a MBUF system may be as equitable as the current fuel tax system (*80*). However, additional study of potential impacts to lower-income road users may be required to avoid imposing an undue burden. While higher rates per mile would have greater influence on driver behavior, fees may need to be capped at a maximum amount to not unduly burden the worst-performing drivers. Consideration could also be given to utilizing revenues from the MBUF to improve transit options, which could benefit low-income residents.

Finally, the amount of desired data must be considered. While yearly odometer checks are a simple way to assess a mileage-based fee, additional data would be needed to better address air quality concerns through mileage-based pricing. Second-by-second speed data would be necessary to implement the system demonstrated in this project, and location data would be desirable. However, policy makers would have to address privacy concerns and determine how to collect such data. Not all vehicles are currently equipped with GPS devices, and the benefit of improved data would have to be weighed against the cost of obtaining it.

7.7: Concluding Remarks

The above examples of two different vehicles show how this performance measurement and pricing framework could be used in a real-world setting. The data used to determine performance were actual GPS data. Some assumptions were made, especially regarding system-level performance, but actual use of this framework would result in real values that could be used in the same manner. Although this framework is fairly theoretical at this point, it could form the basis for a real-world adaptation, depending on the needs of the agency using it. Many inputs can be changed if desired, such as the importance given to different pollutant types, the desired base mileage fee, and the increase of fees based on time and location. Finally, application to heavy-duty vehicles would be quite similar, with the proper data available to calibrate the performance measures. The next section states final conclusions.

8. CONCLUSION

The goal of this research was to develop a MBUF that incorporated air quality goals through the use of performance measurements. A framework of performance measures was developed that addresses multiple aspects of transportation that affect air quality. Overall air quality performance was then translated into an appropriate MBUF that would help achieve air quality goals. Use of this performance measurement and pricing framework was demonstrated in a small case study. This section gives a brief overview of the research process and results.

8.1: General Findings

In this research, performance measures were selected that relate transportation to the emission of air pollutants. Improved performance (i.e. use of new vehicles, fewer miles traveled, changes to driving behavior, etc.) would contribute to achievement of objectives, which would in turn contribute to achievement of air quality and energy goals. The desired air quality and energy goals used in this research are:

- Reduce pollutant emissions;
- Reduce greenhouse gas emissions;
- Reduce impacts on human health; and
- Reduce impacts on the environment.

Selected measures for this research include:

1. Vehicle-miles traveled;
2. Vehicle-miles traveled in certain locations and at certain times;
3. Vehicle emissions rating;
4. Vehicle fuel economy;
5. Vehicle age;
6. Trips on transit;
7. Time traveled at speed greater than optimal air quality speed;
8. Time spent aggressively accelerating/braking; and
9. Participation in driver training.

While Measures 6 and 9 do not directly contribute to decreasing emission rates, they do relate to the framework goals as they would indirectly reduce overall emissions by decreasing miles driven. Measures 1 and 2 contribute to the total amount of pollutants emitted by the vehicle, as emission rates are given as a per-mile amount. The remaining measures do directly impact the emission rate of the vehicle. Measures 3, 4, and 5 relate to specific characteristics of the vehicle itself, while Measures 7 and 8 relate to driver behavior. Measures 1 and 2 are also related to driver behavior, mileage, which is easier for a driver to change. Measures that relate to aspects of the vehicle itself are more difficult for an individual to change, and would likely only change in the long-term, as change would require purchase of a different vehicle. Both types of measures, however, are desirable and useful.

8.1.1: Relationship between Driving Behavior and Pollutant Emissions

One step undertaken in this research was to better define the relationship between driver behavior and resulting changes in emission rates. While emissions were generally expected to increase with 'aggressive driving' behaviors, the exact relationship was not known. Actual driving behavior was analyzed for Measure 7 (time traveled at speed greater than optimal air quality speed) and Measure 8 (time spent aggressively accelerating/braking). This analysis was used to establish the threshold acceleration levels used to define 'hard' acceleration and deceleration, which was taken as the 85th percentile for different speed categories. Additionally, analysis of several speed profiles was studied and graphed to show the relationship between emission rates and aggressive driving behavior. The aggressive driving behaviors considered for this research include the percent of highway driving that is above 60 mph and the percent of acceleration/deceleration that is considered 'hard.' The EPA MOVES model was used to produce emission rates for each speed profile for CO_2, VOC, NOx, CO, and $PM_{2.5}$. While the rate of increase was different for each pollutant type, the emission rates did increase with aggressive driving behavior, as expected. The major exception was the emission of NOx by motorcycles, which significantly decreased with aggressive driving. These results were used in later analysis to estimate emission rates for light-duty vehicles with driving behavior as a consideration. As drive-cycles for heavy-duty vehicles are typically different from those for light-duty vehicles, further analysis would be necessary to obtain relationships between behavior and emissions for heavy-duty vehicles.

8.1.2: Use of Performance Measurement to Meet Air Quality Goals

For this framework, the following measures were combined to obtain approximate emission rates for an individual:

- Measure 3 – Vehicle emissions rating;
- Measure 4 – Vehicle fuel economy;
- Measure 5 – Vehicle age;
- Measure 7 – Time traveled at speed greater than optimal air quality speed; and
- Measure 8 – Time spent aggressively accelerating/braking.

Combining performance in this way allows performance on several measures to be compared to system-level averages and other individuals at one time. Converting these measures to one emission rate simplifies this comparison as the overall performance is converted into one value with one unit of measure (i.e., grams per mile). This one value can be compared to many other individuals, including vehicles in other vehicle classes, if desired. Aggressive driving behavior performance was converted to scaling factors based on the amount by which that performance was expected to affect emissions. Similarly, scaling factors were developed to adjust base emissions of carbon dioxide based on average fuel efficiency. A scaling factor was also used reward users that have vehicles with high (good) EPA Air Pollution Scores. This scaling factor decreases the base emission rate to the standard that vehicle met for several pollutant types, as the Air Pollution Score reflects maximum allowable pollutant levels. Vehicle age is used to obtain base emission rates for an individual, based on MOVES results using national averages.

A final performance score was desired based on the above measures in order to combine all the considered pollutants. While emissions of each pollutant are given in grams per mile, the scale of emissions varies greatly among the pollutants used. Thus, combining the values for all pollutant types would not be well represented by simply adding or averaging the emission rates. Converting the emission rates to a score between 0 and 100 allows the air quality performance of a vehicle to be combined on the same scale. Likely distributions of emissions for each pollutant type were determined, allowing an individual's performance score for each pollutant type to be calculated based on their approximate emission rates. These resulting scores could then be better combined into a final performance score for the individual that can be compared to an average system-level score for the vehicle class. This final score accounts for performance on five performance measures as well as the resulting effect on five pollutant types. Importance placed on different pollutants can also be accounted for using weights. Great simplification is thus obtained through computing this final performance score, which is later used to calculate the mileage fee that should be assessed to the user.

The performance measures related to mileage are used later, and resulting mileage fees are directly applied to mileage. Finally, Measures 6 and 9 were suggested to apply to some sort of waiver or reduction in the final amount owed by an individual, rather than directly affecting the mileage-based fee. This reflects the fact that trips on transit and eco-driving training, while contributing overall to air quality goals, do not directly affect emission rates of a vehicle. Trips on transit do have a direct impact on mileage, which would result in an overall lower cost to the user and lower pollutant emissions.

8.1.3: Linking Mileage-Based User Fees to Performance Measures

Based on literature, MBUFs have been examined for revenue generation, but have also been examined to address policy goals such as congestion reduction, recovering maintenance costs, and encouraging mode shifts. Addressing congestion problems may simultaneously address air quality goals, even if that was not the intention of the pricing system. For example, reductions in vehicle trips due to pricing would contribute to a reduction in emissions. However, for this research, the primary intention is the reduction of air pollution and energy consumption. Therefore, pricing is used with the intention to change driver behavior in a way that will reduce vehicle emissions.

One potential method discussed for linking air quality concerns to pricing was to determine the external cost of vehicle emissions and charge users their contribution. External costs include negative impacts on human health and the environment caused by vehicle emissions. For the example provided in this research, a base mileage fee of two cents per mile was used, based on the approximate value per mile of current state and federal fuel taxes. This base fee is then adjusted for each individual based on their performance score relative to the average performance score. In addition, higher fees can be used for mileage that occurred in certain places or at certain times, such as peak-hour mileage.

Finally, some sort of feedback loop is desirable for this type of pricing framework. As the idea behind pricing is to meet air quality goals, the effect of pricing on performance must be identified. For simplification, changes in vehicle mileage were given primary consideration, as mileage significantly affects the total emissions produced by an individual. Using transportation elasticity values is suggested to relate desired mileage changes to required changes in pricing. If this framework were used, actual data would be especially useful as well to determine actual impacts of pricing on behavior changes and determine true elasticities.

8.1.4: Performance Framework and Results of Case Study

The case study undertaken in the last section illustrates how the performance measurement and pricing framework could be used. The framework was applied to actual travel information for two individuals. Vehicle characteristics and driver behavior determined performance measurement results, which were used to obtain a final performance score. The final score for the individual and the assumed average score across the system were used to determine mileage fees applied to each individual. Although this framework is fairly theoretical at this point, it could be used in a real-world situation, or form the basis for a real-world adaptation. The framework is also fairly flexible, and can be altered to suit the needs of any agency using it. Many inputs can be changed if desired, such as the importance given to different pollutant types, the desired base mileage fee, and the increase of fees based on time and location.

With implementation of such a pricing framework, mileage driven would likely decrease, as the price per mile would be more visible to drivers than the current fuel tax. Improvement in driving behavior could also be achieved on a short-term basis, although public education efforts would likely be necessary to help roadway users understand how to improve their performance and reduce the amount paid per mile. Public outreach, and especially use of a pilot program, is encouraged to help roadway users understand any pricing framework and to address concerns, such as privacy concerns. A pilot program would also be useful for collecting real-world data for calibration purposes and for trouble-shooting prior to full implementation.

Long-term impacts of pricing to improve air quality may include citizens moving closer to employment areas, increased use of telecommuting and flexible work hours, increased transit usage, and a newer vehicle fleet with improved average fuel efficiency and lower average pollutant emissions. However, consideration must be given to equity concerns, as lower-income roadway users may have fewer options in terms of improving their vehicle characteristics or change driving patterns. The implementing agency may consider capping fees at a maximum amount to not unduly burden the worst-performing drivers.

Policy makers would need to determine how much data to collect and the method for collecting it. Not all vehicles are currently equipped with GPS, but second-by-second speed data would be necessary to implement the system demonstrated in this project, and location data would be desirable. Increased data would help to address air quality goals, but the benefit of improved data would have to be weighed against the cost of obtaining it.

8.2: Recommendations for Future Work

The area of mileage pricing, especially to address desired policy goals, is currently an important area of research. The research presented in this thesis represents one approach to using MBUFs to address air quality concerns. Use of performance measurement is certainly helpful for relating goals to appropriate pricing that will improve overall system performance. Through performance measurement, multiple characteristics of vehicles and driving behaviors can be addressed. Similar approaches could be used to address many other policy goals such as equity, and could lead to future research opportunities. Elasticity values could be used to predict impacts of such a system to different policy goals.

In addition, other research efforts could significantly contribute to the framework developed in this research. With additional data, estimation methods could be further refined, and assumptions that were made could be better defined. As only a small data set was used to evaluate the effect of aggressive driving behaviors on emissions, a more extensive data set could yield more accurate results. Data for heavy-duty vehicles could also be investigated. Finally, the case study undertaken for this research was done on a very small scale to demonstrate how the framework would operate. Thus, the opportunity exists for an actual real-world application or field test of this framework. While many pilot studies into the use of MBUFs have been recently undertaken or are currently ongoing, a pilot study that addresses policy goals such as air quality would be beneficial.

8.3: Concluding Remarks

This research provides a method for addressing air quality goals through pricing of travel. Although several assumptions were made, the developed method of measuring performance and translating it into pricing would still be applicable with additional data available. The method could be used in a real-world setting, as shown in the small case study. Air quality concerns are one policy goal that has the potential to be included as an important part in any road-pricing system. While such goals are not currently given priority in mileage-based pricing pilot studies, the framework developed in this research illustrates how air quality could be included in pricing attempts in the future.

REFERENCES

1. Cambridge Systematics, Inc. *Guidelines for Environmental Performance Measurements, Final Report*. Publication NCHRP 25-25, Task 23, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., June 2008.

2. American Lung Association. *Fighting for Healthy Air*. Healthy Air, 2010. http://www.lungusa.org/healthy-air/outdoor/fighting-for-healthy-air/fighting-for-healthy-air.html. Accessed April 23, 2010.

3. Zietsman, J., and L.R. Rilett. *Allocating Responsibility for Mobile Source Emissions*. Presented at the 81st Annual Meeting of the Transportation Research Board, National Research Council, Washington D.C., January 13-17, 2002.

4. Environmental Protection Agency. *Mobile Source Emissions—Past, Present and Future: Pollutants*. U.S. EPA, Washington, D.C., July 9, 2007. http://www.epa.gov/otaq/invntory/overview/pollutants/index.htm. Accessed April 2010.

5. Environmental Protection Agency. *Air Trends: Basic Information.* U.S. EPA, Washington, D.C., April 1, 2010. http://www.epa.gov/airtrends/sixpoll.html. Accessed April 2010.

6. Texas Commission on Environmental Quality. *About Air Pollution in Texas*. TCEQ, Texas, 2002-2010. http://www.tceq.state.tx.us/assistance/P2Recycle/P2Week/airpollution.html. Accessed April 2010.

7. Toxic Substances Hydrology Program. *Volatile Organic Compounds*. U.S. Geological Survey, Department of the Interior, Washington, D.C. http://toxics.usgs.gov/definitions/vocs.html. Accessed April 2010.

8. Rodrigue, J.P. Air Pollutants Emitted by Transport Systems. *The Geography of Transport Systems*, 1998-2010. http://people.hofstra.edu/geotrans/eng/ch8en/appl8en/ch8a1en.html. Accessed March 26, 2010.

9. Puget Sound Clean Air Agency. Air Toxics. *Next Ten Years Fact Sheet*, Puget Sound Area, Washington State, 2005.

10. Texas A&M Transportation Institute. *The Texas Guide to Accepted Mobile Source Emission Reduction Strategies*. TxDOT Contract 50-7XXIA001, Texas Department of Transportation, Texas, August 2007.

11. Zeman, M. *Mobile Source Air Toxics: Overview and Regulatory Background*. Mobile Source Team, Region 2, U.S. Environmental Protection Agency. Presented at the Northern Transportation & Air Quality Summit, Baltimore, Maryland, August 14, 2008.

12. Environmental Protection Agency. *Transportation and Climate: Basic Information.* U.S. EPA, Washington, D.C., March 26, 2010. http://www.epa.gov/OMS/climate/basicinfo.htm. Accessed April 2010.

13. Environmental Protection Agency. *U.S. Greenhouse Gas Inventory.* U.S. EPA, Washington, D.C., April 15, 2010. http://www.epa.gov/climatechange/emissions/usgginventory.html. Accessed April 2010.

14. Environmental Protection Agency. *History of the Clean Air Act.* U.S. EPA, Washington, D.C., December 19, 2008. http://www.epa.gov/air/caa/caa_history.html. Accessed April 2010.

15. Environmental Protection Agency. *Fact Sheet: Final Revisions to the National Ambient Air Quality Standards for Nitrogen Dioxide.* U.S. EPA, Washington, D.C., January, 2010. http://www.epa.gov/air/nitrogenoxides/pdfs/20100122fs.pdf. Accessed April 2010.

16. Environmental Protection Agency. National Ambient Air Quality Standards (NAAQS). *Air and Radiation*, U.S. EPA, Washington, D.C., April 2010. http://www.epa.gov/air/criteria.html. Accessed May 2010.

17. Environmental Protection Agency. *What Are the Six Common Air Pollutants?.* U.S. EPA, Washington, D.C., March 26, 2010. http://epa.gov/air/urbanair/. Accessed April 2010.

18. Environmental Protection Agency. *Particulate Matter: PM Standards.* U.S. EPA, Washington, D.C., April 16, 2010. http://www.epa.gov/air/particlepollution/standards.html. Accessed April 2010.

19. Environmental Protection Agency. *Nitrogen Dioxide Implementation: Programs and Requirements for Reducing Oxides of Nitrogen.* U.S. EPA, Washington, D.C., June 29, 2009. http://www.epa.gov/air/nitrogenoxides/implement.html. Accessed April 2010.

20. Beckman, B., M. Vojtisek-Lom, and P.J. Wilson. *Measurement of Real-World Vehicle Emissions and Evaluation of Emissions Reduction Strategies Using Portable, On-Board Monitoring Systems*. Demonstration project for Texas A&M Transportation Institute, Clean Air Technologies International, Inc., Buffalo, New York, July-August 2003.

21. Marsden, G. *Appraisal of Sustainability: Environment Indicators*. Institute for Transport Studies, University of Leeds, UK, August 2005.

22. Hallmark, S.L., and H. Isebrands. *Evaluating Speed Differences Between Passenger Vehicles and Heavy Trucks for Transportation-Related Emissions Modeling*. Report No. DTFH61-03-P-00336, Center for Transportation Research and Education, Iowa State University. For the Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., July 2004.

23. Vojtisek-Lom, M. *Idle vs. Shutdown and Restart Emissions From In-Use School Buses*. Working Paper, Clean Air Technologies International, Inc., Buffalo, New York, December 11, 2002.

24. Environmental Protection Agency. *Modeling and Inventories: MOBILE6 Vehicle Emission Modeling Software.* U.S. EPA, Washington, D.C., May 10, 2010. http://www.epa.gov/otaq/m6.htm. Accessed May 2010.

25. Environmental Protection Agency. *Frequently Asked Questions on MOBILE6*. Publication EPA420-B-03-013, Assessment and Standards Division, Office of Transportation and Air Quality, U.S. EPA, Washington, D.C., November 2003.

26. Environmental Protection Agency. *Modeling and Inventories: MOVES (Motor Vehicle Emission Simulator).* U.S. EPA, Washington, D.C., May 26, 2010. http://www.epa.gov/otaq/models/moves/. Accessed May 2010.

27. Environmental Protection Agency. *EPA Releases MOVES2010 Mobile Source Emissions Model: Questions and Answers*. Publication EPA-420-F-09-073, Office of Transportation and Air Quality, U.S. EPA, Washington, D.C., December 2009.

28. Zietsman, J., M. Farzaneh, S. Park, D.W. Lee, and H. Rakha. *Expanding MOBILE6 Rates to Accommodate High Speeds*. Center for Air Quality Studies, Texas A&M Transportation Institute, Texas A&M University, sponsored by the Houston Advanced Research Center, Texas, August 2007.

29. General Accounting Office. *Performance Measurement and Evaluation: Definitions and Relationships*. Publication GAO-05-739SP, U.S. General Accounting Office, Washington, D.C., May 2005.

30. Thor, C.G. How to Find, Select, and Display Performance Measures in Government. *Cost Management*, Vol. 17, No. 3, ABI/INFORM Global, May/June 2003, pp. 31-38.

31. Lebas, M.J., Performance Measurement and Performance Management. *International Journal of Production Economics*, Vol. 41, 1995, pp. 23-35.

32. Hatry, H.P. *Performance Measurement: Getting Results, Second Edition*. The Urban Institute Press, Washington, D.C., 2006.

33. Kaufman, R. Preparing Useful Performance Indicators. *Training and Development Journal*, Vol. 42, No. 9, ABI/INFORM Global, September 1988, pp. 80-83.

34. Behn, R.D. Why Measure Performance? Different Purposes Require Different Measures. *Public Administration Review*, Vol. 63, No. 5, September/October 2003, pp. 586-606.

35. Abbott, E.E., J. Cantalupo, and L.B. Dixon. Performance Measures: Linking Outputs and Outcomes to Achieve Goals. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1617*, Transportation Research Board of the National Academies, Washington, D.C., 1998, pp. 90-95.

36. Griffis, S.E., M. Cooper, T.J. Goldsby, and D.J. Closs. Performance Measurement: Measurement Selection Based Upon Firm Goals and Information Reporting Needs. *Journal of Business Logistics*, Vol. 25, No. 2, 2004, pp. 95-118.

37. Cambridge Systematics, Inc. *NCHRP Report 446: A Guidebook for Performance-Based Transportation Planning.* National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., 2000.

38. Beschen, D., R. Day, G. Jordan, and H. Rohm. Collecting Data to Assess Performance. *The Performance-Based Management Handbook,* Vol. 4, Training Resources and Data Exchange, Performance-Based Management Special Interest Group, September 2001.

39. Persad, K.R. *TxDOT Revenue and Expenditure Trends*. Presented at the 2009 CTR Symposium, the Center for Transportation Research, the University of Texas, Austin, Texas, April 8, 2009.

40. Forkenbrock, D.J. Implementing a Mileage-Based Road User Charge. *Public Works Management and Policy*, Vol. 10. No. 2, 2005, pp. 87-100.

41. Baker, R., Goodin, G., Lindquist, E., and Shoemaker, D. *Feasibility of Mileage-Based User Fees: Application in Rural/Small Urban Areas of Northeast Texas*. UTCM Project 08-11-06, University Transportation Center for Mobility, Texas A&M University System, with the North East Texas Regional Mobility Authority, 2008.

42. Litman, T. *Distance Based Charges; A Practical Strategy for More Optimal Vehicle Pricing*. Presented at the 78th meeting of the Transportation Research Board, Session 458, Paper No. 99-0678, January 10-14, 1999.

43. Whitty, J.M., and Imholt, B. *Oregon's Mileage Fee Concept and Road User Fee Pilot Program*. Report to the 73rd Oregon Legislative Assembly, Oregon Department of Transportation, Oregon, 2005.

44. Levinson, D. Equity Effects of Road Pricing: A Review. *Transport Reviews*, Vol. 30, No. 1, January 2010, pp. 33-57.

45. DeCourla-Souza, P. Estimating Benefits from Mileage-Based Vehicle Insurance, Taxes, and Fees. In *Transportation Research Record: Journal of the Transportation Research Board,* No. 1812, Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 171-178.

46. Litman, T. *Distance-Based Vehicle Insurance as a TDM Strategy*. Victoria Transport Policy Institute, Victoria, BC, Canada, 2009.

47. Litman, T. *Transportation Cost and Benefit Analysis: Techiniques, Estimates, and Implications*. Victoria Transport Policy Institute, Victoria, BC, Canada, 2009.

48. Whitty, J.M. and J.R. Svadlenak. Discerning the Pathway to Implementation of a National Mileage-Based Charging System. *Special Report 299: A Transportation Research Program for Mitigating and Adapting to Climate Change and Conserving Energy*. Transportation Research Board of the National Academies, Washington, D.C., October 29, 2009.

49. Komanoff, C. *Environmental Consequences of Road Pricing*. A scoping paper for the Energy Foundation, Komanoff Energy Associates, New York, 1997.

50. Burris, M. and L. Larsen. *Equity Evaluation of Vehicle Miles Traveled Fees in Texas*. Report 161105-1, Texas A&M Transportation Institute, Texas A&M University, sponsored by the Southwest Region University Transportation Center, Texas, August 2007.

51. Office of Regulatory Analysis and Evaluation. *Corporate Average Fuel Economy for MY 2011: Passenger Cars and Light Trucks: Final Regulatory Impact Analysis*. National Center for Statistics and Analysis, National Highway Traffic Safety Administration, United States Department of Transportation, Washington D.C., March 2009.

52. International Transport Danmark and Dansk Speditører. *The German Lkw-Maut: Calculation Models and Conditions*. International Transport Danmark and Dansk Speditører , Denmark, June 2003.

53. Litman, T. *Distance-Based Vehicle Insurance As a TDM Strategy*. Victoria Transport Policy Institute, Victoria, BC, Canada, June 8, 2011.

54. Bordoff, J.E., and P.J. Noel. *Pay-As-You-Drive Auto Insurance: A Simple Way to Reduce Driving-Related Harms and Increase Equity*. Discussion Paper 2008-09, The Hamilton Project, The Brookings Institution, Washington, D.C., July 2008.

55. Progressive Insurance. *How Snapshot Works*. Progressive Insurance, 2012. http://www.progressive.com/auto/snapshot-how-it-works.aspx. Accessed January 2012.

56. Abou-Zeid, M., M. Ben-Akiva, K. Tierney, K.R. Buckeye, and J.N. Buxbaum. Minnesota Pay-As-You-Drive Pricing Experiment. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2079,* Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 8-14.

57. Parry, I.W.H., M. Walls, and W. Harrington. *Automobile Externalities and Policies*. Publication RFF DP 06-26, Resources for the Future, Washington, D.C., June 2006, Revised January 2007.

58. Rothengatter, W., and C. Doll. Design of a User Charge for Heavy-Duty Vehicles on German Motorways Considering the Objectives of Efficiency, Fairness and Environmental Protection. *IATSS Research*, Vol. 26, No. 1, 2002, pp. 6-16.

59. Whitty, J.M. *Oregon's Mileage Fee Concept and Road User Fee Pilot Program*. Oregon Department of Transportation, Oregon, November 2007.

60. Mitchell, G. Forecasting Environmental Equity: Air Quality Responses to Road User Charges in Leeds, UK. *Journal of Environmental Management*, Vol. 77, Issue 3, November 2005, pp. 212-226.

61. Forkenbrock, D.J. Policy Options for Varying Mileage-Based Road User Charges. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2079*, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 29-36.

62. Litman, T. *Pay-As-You-Drive Pricing in British Columbia*. Victoria Transport Policy Institute, Victoria, BC, Canada, November 18, 2008.

63. Buxbaum, J. *Mileage-Based User Fee Demonstration Project: Pay-As-You-Drive Experimental Findings*. Cambridge Systematics, Inc., for Minnesota Department of Transportation, Cambridge, Massachusetts, March 2006.

64. May, A.D. Road Pricing: An International Perspective. *Transportation*, Vol. 19, 1992, pp. 313-333.

65. Litman, T. *Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior*. Victoria Transport Policy Institute, Victoria, BC, Canada, November 24, 2011.

66. Texas Department of Transportation. *TxDOT 2011-2015 Strategic Plan*. Draft posted for public comment, Strategic Policy & Performance Management Office, TxDOT, Texas, April 16, 2010.

67. Environmental Protection Agency. *Vehicle Emission Standards and Air Pollution Scores*. Office of Transportation and Air Quality, U.S. EPA, Washington, D.C., December 2011. http://www.epa.gov/greenvehicles/summarychart.pdf. Accessed December 2011.

68. Environmental Protection Agency. *Green Vehicle Guide*. U.S. EPA, Washington, D.C., January 10, 2012. http://www.epa.gov/greenvehicles/Index.do. Accessed January 10, 2012.

69. Department of Energy and Environmental Protection Agency. *Fuel Economy*. Energy Efficiency and Renewable Energy, U.S. DOE and Office of Transportation & Air Quality, U.S. EPA, Washington, D.C., December 15, 2011. http://www.fueleconomy.gov/. Accessed December 2011.

70. Barkenbus, J.N. Eco-Driving: An Overlooked Climate Change Initiative. *Energy Policy*, Vol. 38, 2010, pp. 762-769.

71. U.S Energy Information Administration. *Voluntary Reporting of Greenhouse Gases Program.* U.S. EIA, Washington, D.C., January 31, 2011. http://www.eia.gov/oiaf/1605/coefficients.html#tbl2. Accessed May 20, 2016 .

72. Google. *Austin, Texas*. Google Maps, 2011. https://www.google.com/maps/place/Austin,+TX/@30.3079823,-97.8938289,11z/data=!3m1!4b1!4m5!3m4!1s0x8644b599a0cc032f:0x5d9b464bd469d57a!8m2!3d30.267153!4d-97.7430608. Accessed November 2011.

73. Environmental Protection Agency. *2011 National Emissions Inventory (NEI) Data*. U.S. EPA, Washington, D.C., September 22, 2016. https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-data. Accessed December 15, 2016.

74. Matthews, H.S., C. Hendrickson, and A. Horvath. External Costs of Air Emissions from Transportation. *Journal of Infrastructure Systems*, Vol. 7, No. 1, March 2001, pp. 13-17.

75. U.S. Department of Transportation. *National Transportation Statistics*. Bureau of Transportation Statistics, Research and Innovative Technology Administration, U.S. Department of Transportation, Washington, D.C., 2014. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/NTS_Entire_14Q3.pdf. Accessed January 5, 2015.

76. Borjesson, M., J. Eliasson, M.B. Hugosson, and K. Brundell-Freij. The Stockholm Congestion Charges – 5 Years On. Effects, Acceptability and Lessons Learnt. *Transport Policy*, Vol. 20, March 2012, pp. 1-12.

77. Lee, D.B. and M. Burris. *HERS-ST Highway Economic Requirements System – State Version: Technical Report – Appendix C: Demand Elasticities for Highway Travel*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., April 29, 2015. https://www.fhwa.dot.gov/asset/hersst/pubs/tech/tech11.cfm. Accessed December 21, 2016.

78. U.S. Department of Transportation. *Cash for Clunkers Wraps Up With Nearly 700,000 Car Sales and Increased Fuel Efficiency*. National Highway Traffic Safety Administration, U.S. Department of Transportation, Washington, D.C., 2009. http://www.nhtsa.gov/About+NHTSA/Press+Releases/2009/Cash+for+Clunkers+Wraps+up+with+Nearly+700,000+car+sales+and+increased+fuel+efficiency,+U.S.+Transportation+Secretary+LaHood+declares+program+%E2%80%9Cwildly+successful%E2%80%9D. Accessed January 20, 2015.

79. Carlson, D. and Z. Howard. *Impacts of VMT Reduction Strategies on Selected Areas and Groups.* Washington State Transportation Center, for Washington State Department of Transportation, December 2010.

80. Larsen, L., M. Burris, D. Pearson, and P. Ellis. Equity Evaluation of Fees for Vehicle Miles Traveled in Texas. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2297*, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 11-20.

APPENDIX A

SPEED PROFILES USED TO EVALUATE HIGH SPEED EFFECTS

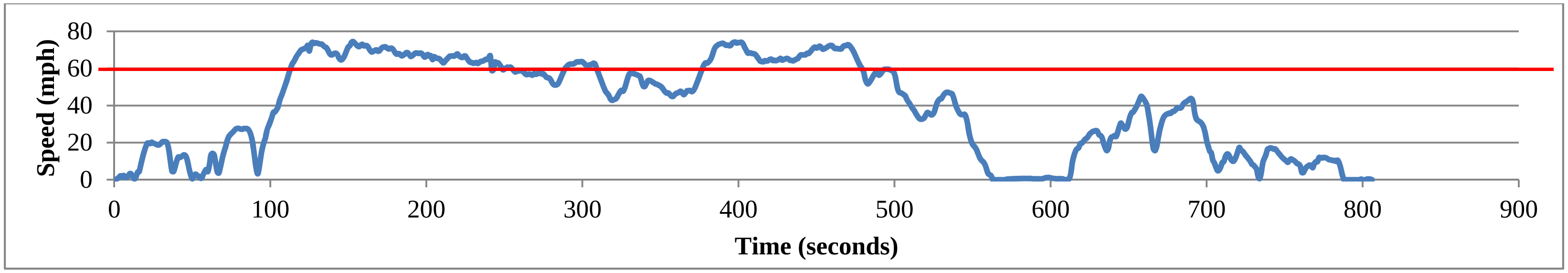

Figure A-1: Vehicle speed profile 1.

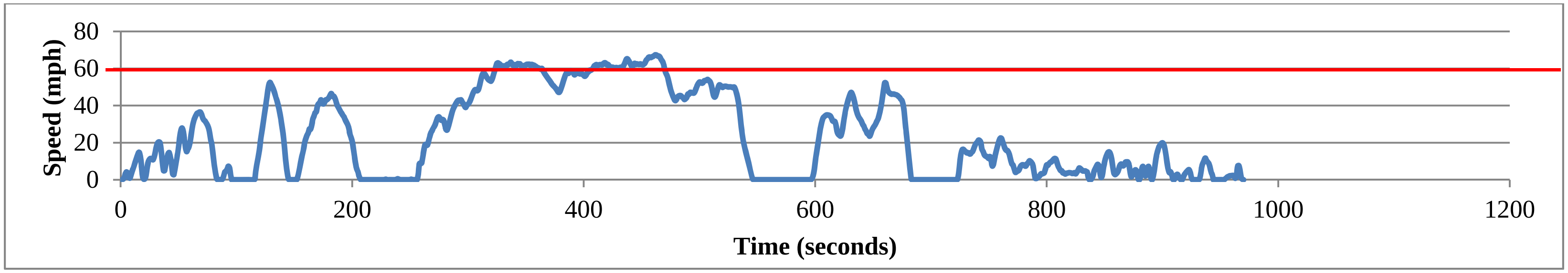

Figure A-2: Vehicle speed profile 2.

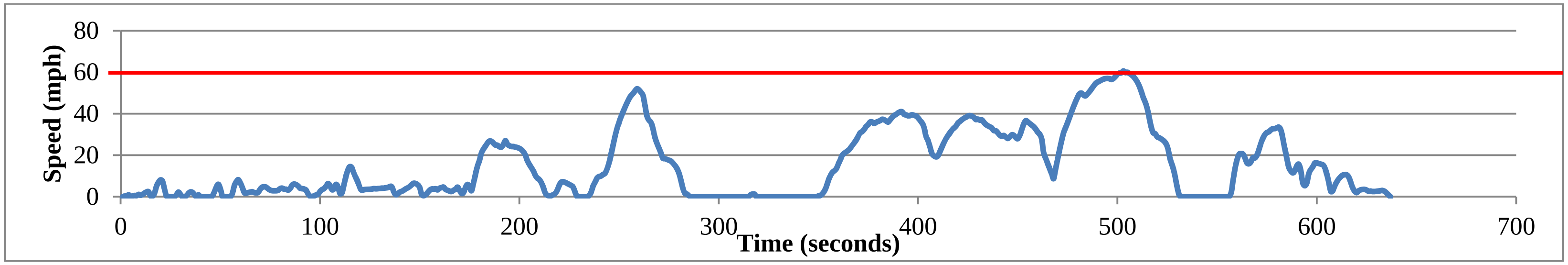

Figure A-3: Vehicle speed profile 3.

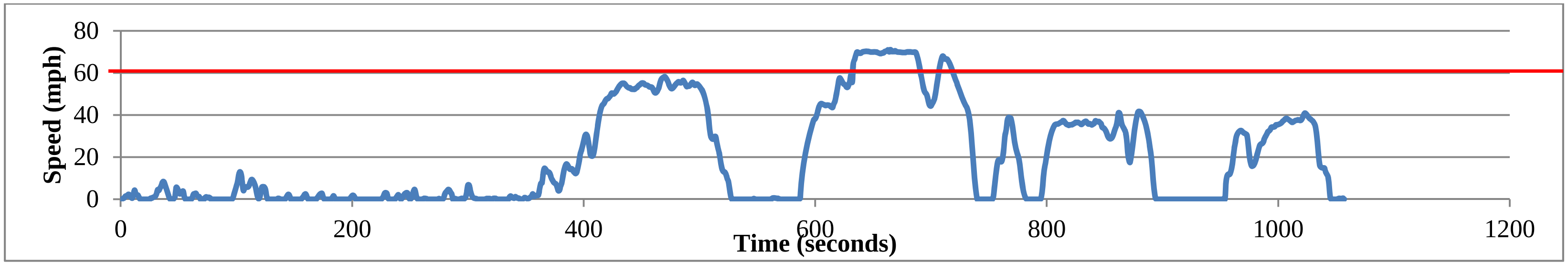

Figure A-4: Vehicle speed profile 4.

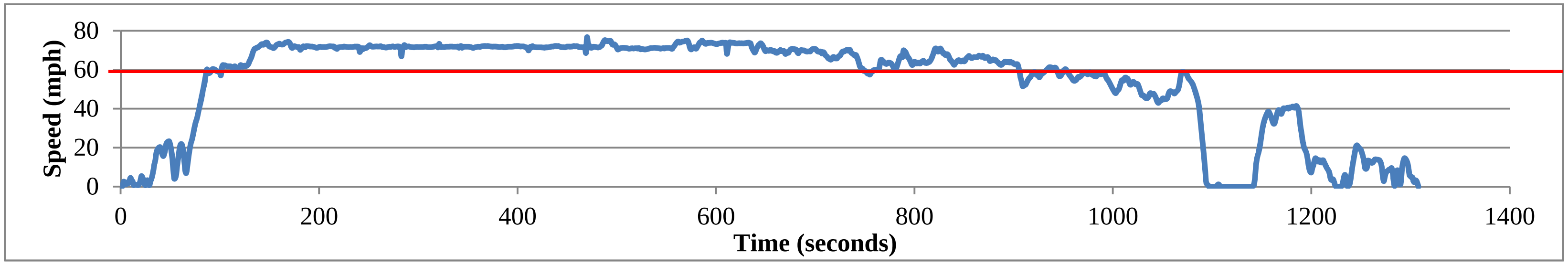

Figure A-5: Vehicle speed profile 5.

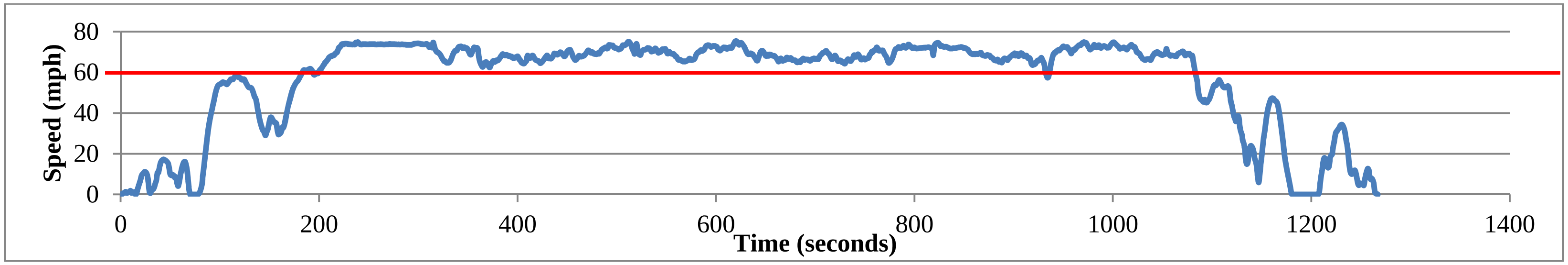

Figure A-6: Vehicle speed profile 6.

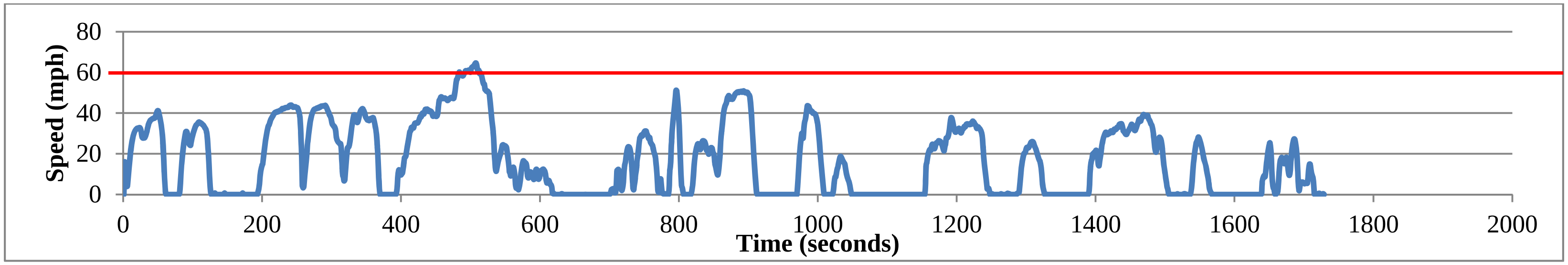

Figure A-7: Vehicle speed profile 7.

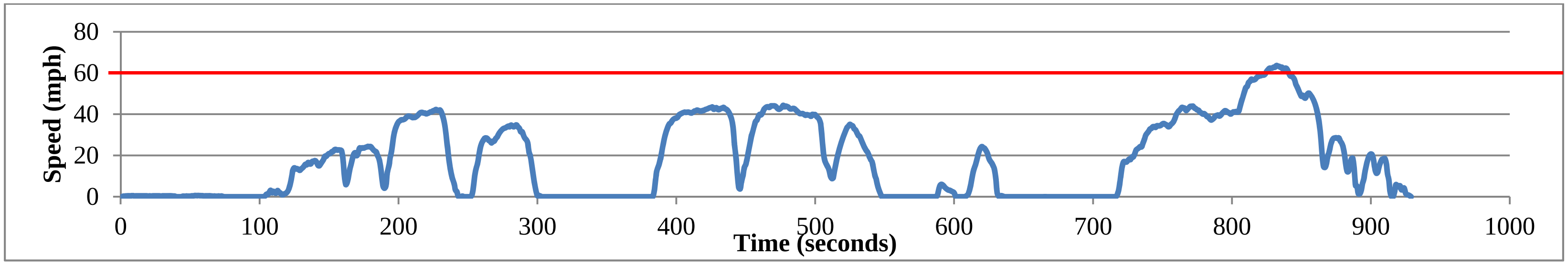

Figure A-8: Vehicle speed profile 8.

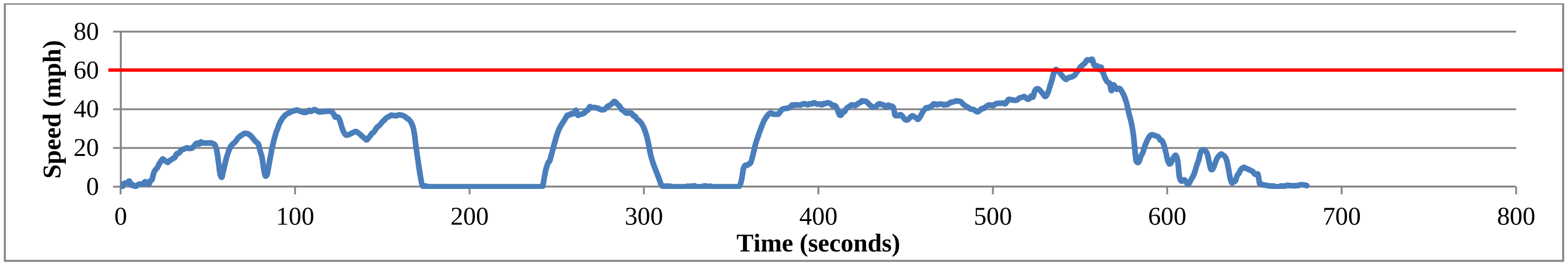

Figure A-9: Vehicle speed profile 9.

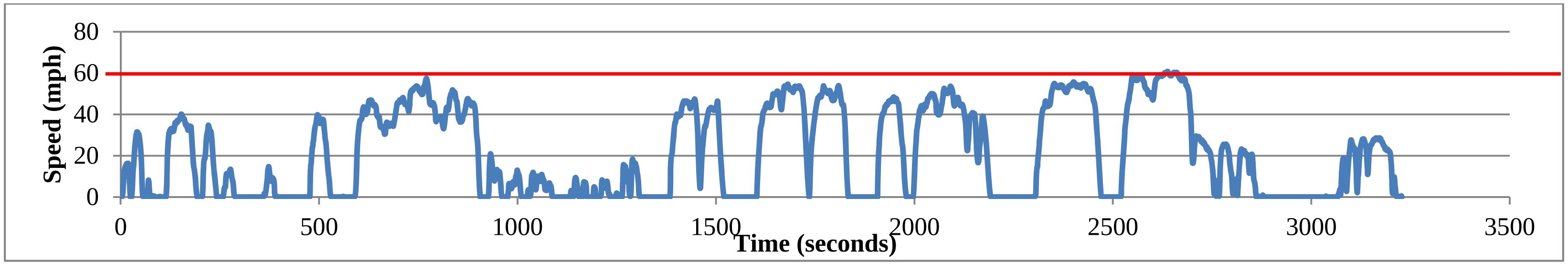

Figure A-10: Vehicle speed profile 10.

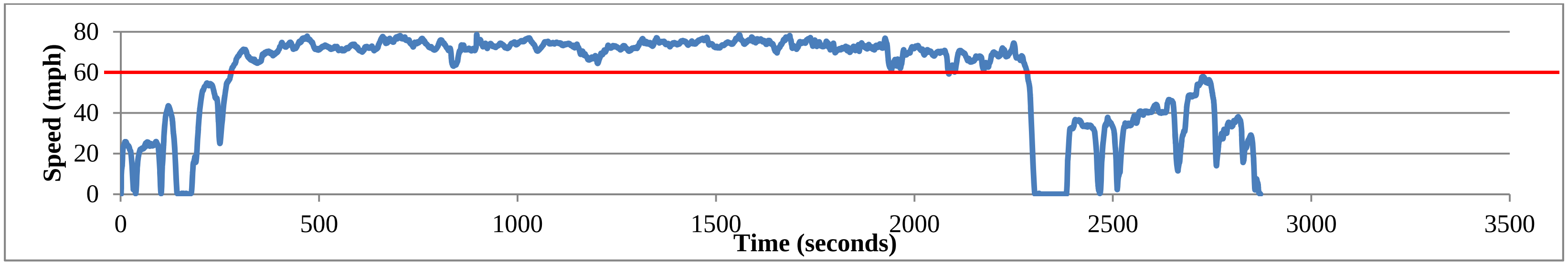

Figure A-11: Vehicle speed profile 11.

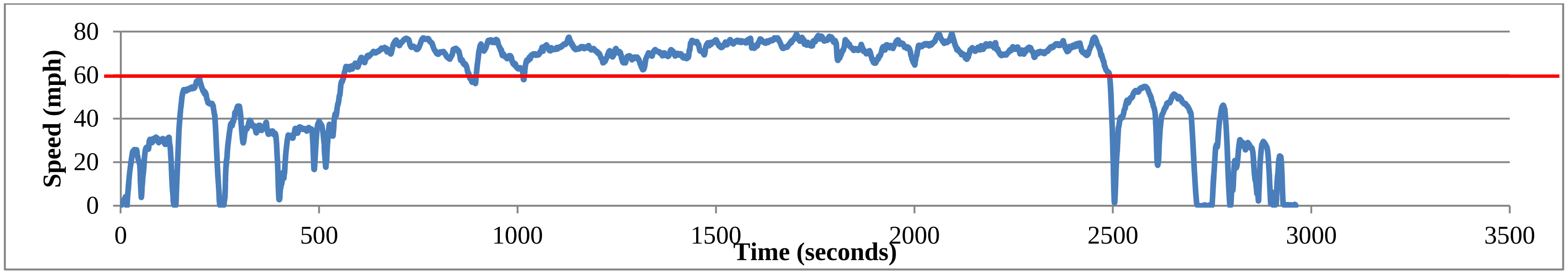

Figure A-12: Vehicle speed profile 12.

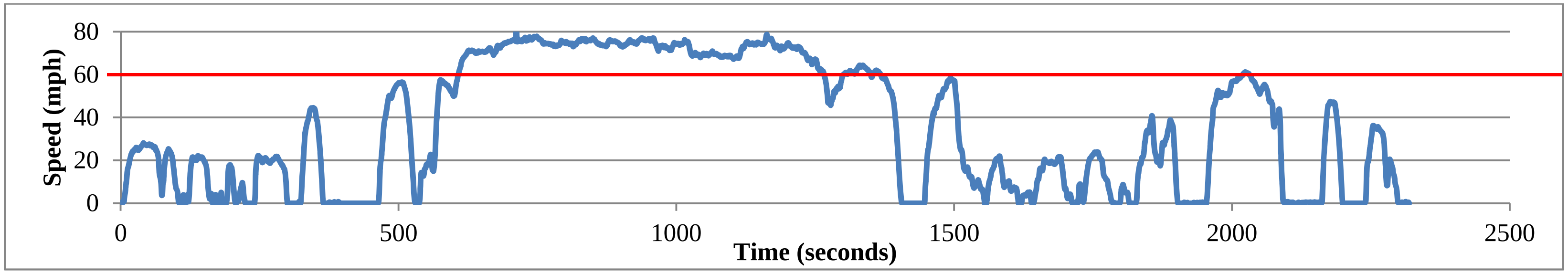

Figure A-13: Vehicle speed profile 13.

APPENDIX B

NATIONAL EMISSION RATES FOR URBAN RESTRICTED AND UNRESTRICTED ACCESS

Table B-1: National Emissions Rates for Passenger Cars

Amount of Pollutant in g/mile on Urban Restricted Access Facilities														
Model Year	35 mph (ID 9)							60 mph (ID 4)						
	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2
2010+	381.064	0.0050	0.0393	1.3964	0.0093	0.0025	0.0074	587.834	0.0039	0.0353	0.8989	0.0073	0.0025	0.0114
2007-2009	377.026	0.0082	0.0578	1.8756	0.0123	0.0028	0.0073	581.543	0.0064	0.0567	1.3032	0.0096	0.0027	0.0113
2004-2006	383.137	0.0199	0.1381	3.4781	0.0242	0.0036	0.0074	590.853	0.0161	0.1576	3.0094	0.0196	0.0035	0.0114
2000-2003	380.939	0.0814	0.5942	5.5606	0.0847	0.0076	0.0074	588.983	0.1162	0.8106	5.6528	0.1192	0.0044	0.0114
1996-1999	372.660	0.2354	1.0807	8.9323	0.2409	0.0125	0.0072	581.242	0.3971	1.5580	9.7709	0.4062	0.0081	0.0113
1992-1995	368.777	0.4410	1.9175	13.1234	0.4598	0.0221	0.0071	575.783	0.8004	2.6942	16.2190	0.8345	0.0133	0.0112
1988-1991	368.879	0.6988	2.2385	18.5022	0.7324	0.0449	0.0071	583.952	1.2798	3.1068	23.6545	1.3412	0.0258	0.0113
pre-1988	419.459	1.1880	2.2719	29.3862	1.2125	0.0696	0.0081	657.708	2.2002	3.0878	38.5444	2.2452	0.0292	0.0127
Amount of Pollutant in g/mile on Urban Unrestricted Access Facilities														
Model Year	35 mph (ID 9)							60 mph (ID 4)						
	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2
2010+	363.398	0.0038	0.0330	0.8560	0.0070	0.0019	0.0070	601.850	0.0054	0.0611	1.3105	0.0101	0.0032	0.0117
2007-2009	359.543	0.0062	0.0493	1.1841	0.0093	0.0020	0.0070	595.415	0.0088	0.0939	1.8302	0.0133	0.0035	0.0115
2004-2006	365.367	0.0152	0.1219	2.4087	0.0185	0.0026	0.0071	604.955	0.0219	0.2438	3.8251	0.0267	0.0045	0.0117
2000-2003	363.327	0.0704	0.5457	4.1503	0.0730	0.0034	0.0070	602.818	0.1278	1.1572	6.6235	0.1317	0.0080	0.0117
1996-1999	355.603	0.2136	1.0025	6.9043	0.2185	0.0063	0.0069	594.028	0.4162	2.1518	10.8910	0.4257	0.0130	0.0115
1992-1995	351.903	0.4086	1.7598	10.8050	0.4259	0.0134	0.0068	588.069	0.8332	3.8005	17.7216	0.8686	0.0206	0.0114
1988-1991	352.795	0.6597	2.0607	15.9592	0.6912	0.0265	0.0068	592.995	1.3205	4.2806	25.9515	1.3838	0.0405	0.0115
pre-1988	401.421	1.1419	2.1563	27.4349	1.1655	0.0454	0.0078	670.637	2.2840	4.1317	42.9265	2.3309	0.0551	0.0130

Table B-2: National Emissions Rates for Passenger Trucks

Amount of Pollutant in g/mile on Urban Restricted Access Facilities														
Model Year	35 mph (ID 9)							60 mph (ID 4)						
	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2
2010+	476.599	0.0181	0.1568	1.9439	0.0213	0.0042	0.0092	716.769	0.0325	0.2117	1.4064	0.0384	0.0026	0.0139
2007-2009	512.000	0.0211	0.1790	2.5050	0.0245	0.0049	0.0099	769.926	0.0343	0.2335	1.8283	0.0399	0.0031	0.0149
2004-2006	545.689	0.0527	0.3519	4.7881	0.0558	0.0070	0.0106	820.441	0.0948	0.4405	3.9840	0.1001	0.0044	0.0159
2000-2003	538.840	0.2021	1.2206	9.9230	0.2038	0.0136	0.0104	811.058	0.3151	1.4884	9.9545	0.3178	0.0039	0.0157
1996-1999	509.330	0.3905	1.7033	14.3081	0.3947	0.0194	0.0099	770.835	0.6644	2.3158	16.4038	0.6717	0.0075	0.0149
1992-1995	469.784	1.0915	3.8226	30.4069	1.1105	0.0271	0.0091	718.191	2.0017	4.9778	33.0379	2.0354	0.0246	0.0139
1988-1991	490.064	1.4315	4.3012	44.4563	1.4965	0.0488	0.0095	747.757	2.6710	5.3078	44.9080	2.7905	0.0380	0.0145
pre-1988	620.383	2.0742	4.4929	53.5031	2.1662	0.0597	0.0120	822.084	4.3118	4.9599	72.2299	4.5023	0.0739	0.0159
Amount of Pollutant in g/mile on Urban Unrestricted Access Facilities														
Model Year	35 mph (ID 9)							60 mph (ID 4)						
	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2
2010+	456.325	0.0160	0.1508	1.3897	0.0188	0.0026	0.0088	733.025	0.0327	0.2795	1.8204	0.0386	0.0042	0.0142
2007-2009	490.221	0.0183	0.1715	1.7996	0.0212	0.0031	0.0095	787.397	0.0356	0.3131	2.3820	0.0413	0.0050	0.0152
2004-2006	522.459	0.0466	0.3350	3.6222	0.0493	0.0044	0.0101	839.054	0.0938	0.6027	4.9066	0.0992	0.0071	0.0163
2000-2003	515.973	0.1870	1.1525	7.8293	0.1886	0.0052	0.0100	829.936	0.3237	2.1007	11.3113	0.3264	0.0111	0.0161
1996-1999	487.777	0.3702	1.6040	11.2857	0.3742	0.0090	0.0094	789.495	0.6695	3.1783	17.5463	0.6768	0.0168	0.0153
1992-1995	449.336	1.0334	3.5769	23.9319	1.0511	0.0172	0.0087	734.780	1.9751	6.7260	35.9406	2.0084	0.0278	0.0142
1988-1991	469.413	1.3553	3.9731	33.4050	1.4165	0.0310	0.0091	764.505	2.6695	7.0950	51.9221	2.7888	0.0476	0.0148
pre-1988	592.124	1.9855	4.2033	46.9027	2.0736	0.0455	0.0115	854.088	4.2840	6.4015	78.9755	4.4735	0.0871	0.0165

Table B-3: National Emissions Rates for Motorcycles

Amount of Pollutant in g/mile on Urban Restricted Access Facilities														
Model Year	35 mph (ID 9)							60 mph (ID 4)						
	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2
2010+	360.709	0.6207	0.5328	9.2804	0.6394	0.0333	0.0070	408.084	1.0678	0.3265	9.6323	1.1000	0.0130	0.0079
2007-2009	360.709	0.7855	0.5454	11.0945	0.8010	0.0333	0.0070	408.084	1.3514	0.3343	11.5153	1.3781	0.0130	0.0079
2004-2006	360.708	1.1151	0.5706	14.7215	1.1243	0.0333	0.0070	408.084	1.9184	0.3497	15.2798	1.9343	0.0130	0.0079
2000-2003	360.709	1.3876	0.7551	20.0057	1.3875	0.0333	0.0070	408.084	2.3873	0.4628	20.7644	2.3871	0.0130	0.0079
1996-1999	352.821	1.2935	0.7207	19.2859	1.2933	0.0333	0.0068	400.606	2.2252	0.4417	20.0172	2.2250	0.0130	0.0078
1992-1995	335.114	1.2774	0.7272	18.7828	1.2863	0.0333	0.0065	383.835	2.1976	0.4457	19.4951	2.2130	0.0130	0.0074
1988-1991	305.115	1.2681	0.7338	18.2750	1.2793	0.0333	0.0059	370.305	2.1817	0.4497	18.9680	2.2010	0.0130	0.0072
pre-1988	298.704	2.0889	0.8313	23.1350	2.0818	0.0333	0.0058	369.195	3.5937	0.5095	24.0123	3.5815	0.0130	0.0072

Amount of Pollutant in g/mile on Urban Unrestricted Access Facilities														
Model Year	35 mph (ID 9)							60 mph (ID 4)						
	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2	CO_2	VOC	NOx	CO	THC	$PM_{2.5}$	SO_2
2010+	344.563	0.6081	0.5088	8.9236	0.6265	0.0187	0.0067	416.841	1.0716	0.3828	10.2047	1.1039	0.0252	0.0081
2007-2009	344.562	0.7696	0.5209	10.6679	0.7849	0.0187	0.0067	416.841	1.3562	0.3918	12.1994	1.3830	0.0252	0.0081
2004-2006	344.563	1.0926	0.5450	14.1555	1.1016	0.0187	0.0067	416.842	1.9253	0.4100	16.1877	1.9413	0.0252	0.0081
2000-2003	344.562	1.3596	0.7212	19.2365	1.3595	0.0187	0.0067	416.841	2.3959	0.5425	21.9981	2.3957	0.0252	0.0081
1996-1999	337.105	1.2673	0.6883	18.5443	1.2672	0.0187	0.0065	409.160	2.2332	0.5178	21.2065	2.2330	0.0252	0.0079
1992-1995	320.364	1.2516	0.6946	18.0607	1.2604	0.0187	0.0062	391.934	2.2055	0.5225	20.6535	2.2209	0.0252	0.0076
1988-1991	293.438	1.2425	0.7008	17.5723	1.2535	0.0187	0.0057	376.598	2.1895	0.5272	20.0950	2.2089	0.0252	0.0073
pre-1988	287.855	2.0467	0.7940	22.2455	2.0398	0.0187	0.0056	374.977	3.6066	0.5972	25.4390	3.5944	0.0252	0.0073