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**DOT Grant No. DTRT06-G-0044**

# Use of Performance Measurement to Include Air Quality and Energy into Mileage-Based User Fees

## *Final Report*

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***Performing Organization***
University Transportation Center for Mobility™
Texas Transportation Institute
The Texas A&M University System
College Station, TX

***Sponsoring Agency***
Department of Transportation
Research and Innovative Technology Administration
Washington, DC

Texas Transportation Institute

**UTCM Project #10-25-50**
**March 2012**

**Technical Report Documentation Page**

| | | |
|---|---|---|
| 1. Report No.<br>UTCM 10-25-50 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>Use of Performance Measurement to Include Air Quality and Energy into Mileage-Based User Fees | | 5. Report Date<br>March 2012<br>6. Performing Organization Code<br>Texas Transportation Institute |
| 7. Author(s)<br>Reza Farzaneh, Kristen Novak, Richard T. Baker, Ginger Goodin | | 8. Performing Organization Report No.<br>UTCM 10-25-50 |
| 9. Performing Organization Name and Address<br>University Transportation Center for Mobility™<br>Texas Transportation Institute<br>The Texas A&M University System<br>3135 TAMU<br>College Station, TX 77843-3135 | | 10. Work Unit No. (TRAIS)<br>11. Contract or Grant No.<br>DTRT06-G-0044 |
| 12. Sponsoring Agency Name and Address<br>Department of Transportation<br>Research and Innovative Technology Administration<br>400 7th Street, SW<br>Washington, DC 20590 | | 13. Type of Report and Period Covered<br>Final Report<br>January 2010 – January 2012<br>14. Sponsoring Agency Code |
| 15. Supplementary Notes<br>Supported by a grant from the US Department of Transportation, University Transportation Centers Program | | |

16. Abstract

Road pricing is an increasingly popular tool for achieving a number of transportation policy related goals and objectives. Addressing environmental concerns is a common goal of road pricing systems in Europe but is less common in the U.S., and frameworks supporting their deployment are less developed. The development of more technologically advanced pricing systems, such as mileage-based user fees (MBUFs) provides platforms for more detailed charging and the achievement of more specific air quality related goals and objectives. This research project is aimed at establishing a framework for levying MBUFs designed to achieve various air quality improvement policy objectives. This research presents the first step toward a pricing framework based on the concept of performance measurement that systematically defines and incorporates potential air quality goals. The process of developing the proposed framework included defining the interactive role of user fees and pricing in roadway transportation operations and identifying air quality performance measures for determining the appropriate vehicle mileage fee price. This framework will be invaluable in more effectively monitoring the air quality and greenhouse gas reduction and mitigation performance of vehicle mileage fee systems.

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|---|---|---|---|
| 17. Key Word<br>Air Quality, Mileage-Based, User Fee, Performance Measure, Emission, Pricing | | 18. Distribution Statement<br>Public distribution | |
| 19. Security Classif. (of this report)<br>Unclassified | 20. Security Classif. (of this page)<br>Unclassified | 21. No. of Pages<br>170 | 22. Price<br>n/a |

**Form DOT F 1700.7 (8-72)** Reproduction of completed page authorized

# Use of Performance Measurement to Include Air Quality and Energy into Mileage-Based User Fees

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## ACKNOWLEDGMENT

Support for this research was provided by a grant from the U.S. Department of Transportation, University Transportation Centers Program to the University Transportation Center for Mobility™ (DTRT06-G-0044).

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## EXECUTIVE SUMMARY

Road pricing is an increasingly popular tool for achieving a number of transportation policy related goals and objectives. Tolling is often utilized for revenue oriented goals such as the generation of funds for capacity expansion, and congestion pricing can be applied to achieve system management oriented goals such as congestion reduction. These types of pricing applications are well established and frameworks for their deployment are already in place. Pricing may also be utilized to achieve environmental related goals, such as air quality improvement or emissions reduction. Addressing environmental concerns is a common goal of road pricing systems in Europe but is less common in the United States, and frameworks supporting their deployment are less developed.

Efficient pricing requires a link between the price charged and the desired objective. For European systems, this means that heavier and older vehicles are charged a higher distance-based fee for travel. However, the development of more technologically advanced pricing systems, such as mileage-based user fees (MBUFs) could provide platforms for more detailed charging and the achievement of more specific air quality related goals and objectives. For example, MBUF systems that rely on data feeds from on-board diagnostic (OBD) connections could potentially levy fees that penalize hard acceleration and braking—driving behaviors that contribute to increased emissions. MBUF systems based on global navigation satellite system (GNSS) technology could levy fees that vary based on where travel is occurring, such that drivers in areas with poor air quality would be assessed a higher distance-based charge.

This research project is aimed at establishing a framework for levying MBUFs designed to achieve various air quality improvement policy objectives. Environmental objectives are often included in road pricing fee applications, but they are often of secondary importance. For those pricing systems where environmental goals are a central component, the fees generally only vary based on a limited number of factors that generally correspond to non-dynamic vehicle characteristics such as vehicle type, emissions class, and weight. This effort is oriented around exploring not only environmental pricing based on static vehicle characteristics, but also on dynamic vehicle and system-wide characteristics such as driving behavior and congestion levels.

The development of a framework for environmental pricing began with the development of broad policy goals. These goals include:

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

These goals were then articulated and defined in terms of specific objectives. These goals and objectives are shown in Table 1.

**Table 1: Policy Goals and Associated Objectives**

| | Objectives: | 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 for a vehicle | ● | ● | | |
| 2 | Discourage driving in a specific sub-area and/or at a specific time | ● | ● | ● | ● |
| 3 | Encourage driving lower emissions vehicles | ● | | ● | |
| 4 | Encourage driving more fuel efficient vehicles | | ● | | ● |
| 5 | Encourage use of public transportation | ● | ● | | |
| 6 | Discourage driving behaviors that increase emissions | ● | ● | ●* | ●* |
| 7 | Encourage freight efficiency and use of preferable modes | ● | ● | | |
| 8 | Encourage participation in training or web-based resources for better driving behavior; e.g., eco driving | ● | ● | | |
| | ** when applied to a specific/applicable sub-area* | | | | |

For each of these objectives, a performance measure was identified. These performance measures were used to build a framework for evaluating how well the pricing system meets its various goals and associated objectives. It was determined that simply having vehicle specific measures would not provide a sufficient framework for the application of a MBUF in this context, as initial rates would be arbitrarily set. Therefore, performance measures were set up to incorporate both individual vehicle characteristics as well as system-wide attributes. Thus, system-wide characteristics such as vehicle miles traveled (VMT) per-capita provide a basis for levying charges at the vehicle specific level. Ultimately, six measures were selected for inclusion in the framework. These measures included:

- Vehicle miles traveled and VMT by time and location;
- Environmental Protection Agency (EPA) vehicle emissions ratings;
- EPA estimated fuel economy;
- Vehicle age;
- Time traveled at speed greater than the optimal speed for air quality (>60 mph); and
- Time spent aggressively accelerating.

Scaling factors were next established for each of these measures to connect them in a systematic manner. If implemented within a pricing system, these scaling factors would be used to adjust fee rates in order to achieve desired level of emissions reduction. For example, scaling factors could be applied at the individual vehicle level in order to promote changes in the vehicle fleet in terms of emissions ratings. The drivers of vehicles with a higher than average emissions rating would be subject to higher fee levels; the scaling factor would determine the exact rate, based on the desired level of emissions in terms of fleet emissions rating. The proposed framework was demonstrated through a couple of sample applications based on real-world Global Positioning System (GPS) data.

# CHAPTER 1: INTRODUCTION

Air quality has increasingly become an important policy consideration—both nationally and worldwide. Now, 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 are cause for concern (*1*). Air pollution negatively impacts the environment, contributing to phenomena such as acidification and global climate change. In addition, air pollution has a negative impact on human health. 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 (*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 through the implementation of pricing. Vehicle mileage fees, where drivers are charged for road use based on distance traveled, are seen as one of the most promising pricing options for achieving air quality goals. Vehicle mileage fees are currently being researched as a solution to transportation funding problems and as a possible replacement for the fuel tax, and could also potentially be used to address congestion. However, using these fees to address other goals such as environmental mitigation and social equity has not been fully explored. Thus, the application of mileage vehicle fees to address air quality problems was studied in this research. To achieve air quality goals with pricing, a system of performance measures was created so that fees can be related to vehicle and driver performance. Pricing to alleviate congestion is based on incentivizing driver behaviors that reduce congestion. Therefore, air quality related fees should be established in such a way as to encourage better performance as it relates to vehicle emissions.

Information obtained through literature review was used to develop an initial set of broad-based goals, or guiding principles, related to air quality and energy use. The set of goals describes the desired outcome of the MBUF system. An initial set of specific objectives was then developed to further define the goals as they relate to transportation. Some objectives may address multiple goals. Finally, potential performance measures were identified for each objective, based primarily on the literature review. The final set of measures, objectives, and overarching goals were organized into a measurement framework that can be used to levy an air quality oriented MBUF system, as illustrated below in Figure 1.

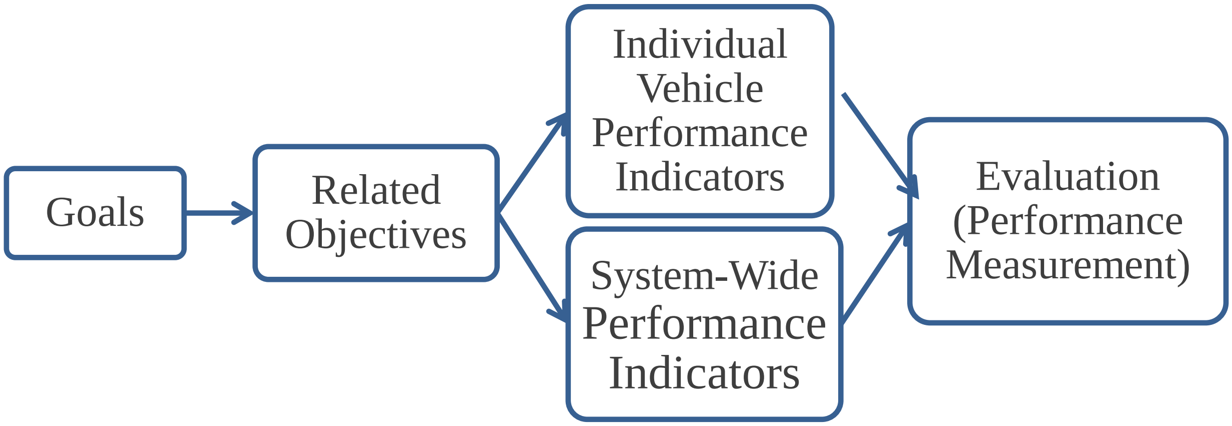


**Figure 1: Performance measurement framework set-up.**

In this project, performance measures were used to quantify two aspects of the transportation system for the purposes of determining an MBUF rate: individual vehicle performance and behavior indicators and system-wide performance indicators. Both individual and system-wide measures are needed, where the performance of individuals is aggregated to represent the total performance across the system. In this way, the eventual fee system should reflect how well the individual performed in light of overall system needs. Drivers that perform better (i.e., have lower emission vehicles, drive fewer miles, drive less aggressive) than average should not be penalized for their performance, and would likely be charged less than average. Drivers that perform worse than average should pay more for emitting pollutants at a higher level.

The effect of performance on emissions for the final set of performance measures was investigated. For example, increased highway speeds and hard acceleration could be expected to increase emission rates, but the relative impact was not known. To determine this, an emissions modeling effort was undertaken where emissions rates were estimated by applying various drive cycles to the performance measures and analyzing them to determine the effect of driving behavior on emission rates. Vehicle characteristics, such as vehicle class, model, and age affect emissions rates as well and were thus included in the modeling effort. General differences in emissions rates among different vehicle types were also investigated for this project. The idea behind this investigation was to relate various degrees of driving behavior and vehicle performance to expected emissions rates. Worse performance relates to greater emission rates, which should result in the individual paying a higher mileage fee.

A general methodology for relating performance to appropriate user fees was then developed. The purpose of the user fee system was to use monetary means to achieve established air quality goals. In this case, the per-mile fee charged to each individual in the system depends on the relative performance of that particular vehicle and driver. Thus, drivers 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 an additional 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 effect across the transportation system as behavior and vehicle fleet composition changes, 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, as they anticipate changes in behavior due to changes in cost. Then, if a specific goal were established, such as a goal to reduce emissions by a specific amount during a specific time period, pricing could be adjusted so that the necessary change in behavior could be achieved. Such a process is illustrated in Figure 2.

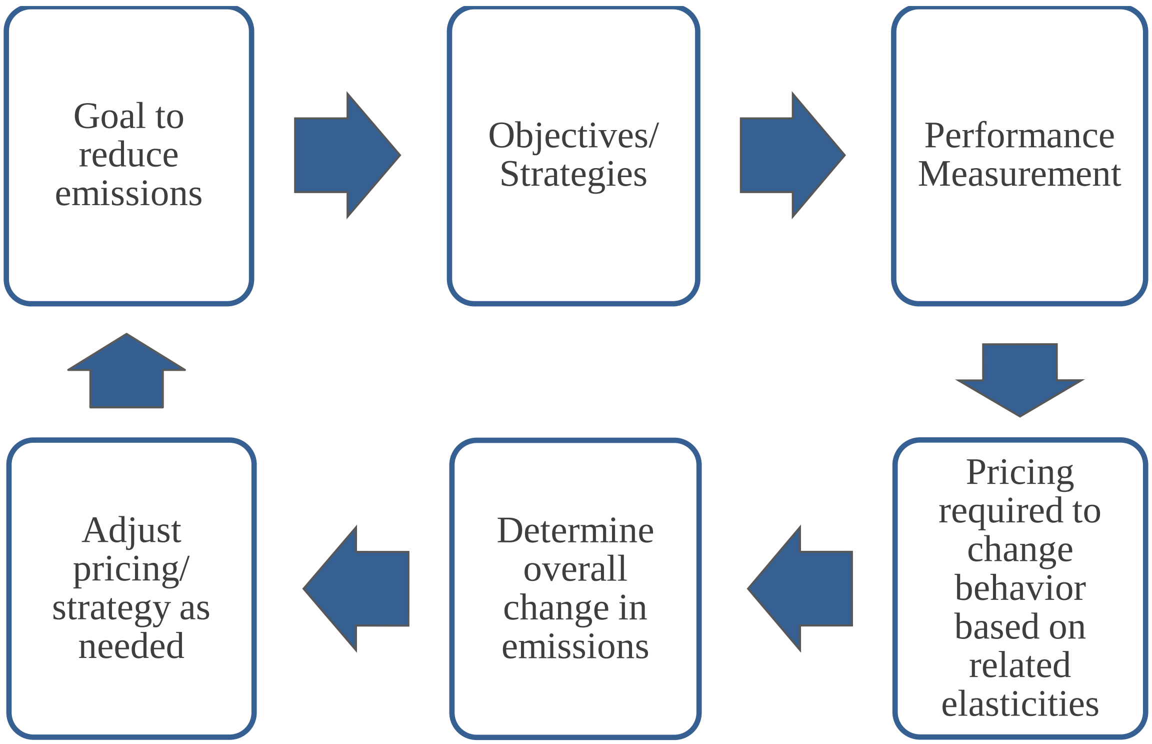


**Figure 2: Pricing process to achieve goals.**

As shown, the process would require feedback so that pricing could be adjusted as needed. Also, measures that have a greater impact on air quality could be given more weight in a pricing framework. An overview of the entire process undertaken for this project is shown in Figure 3.

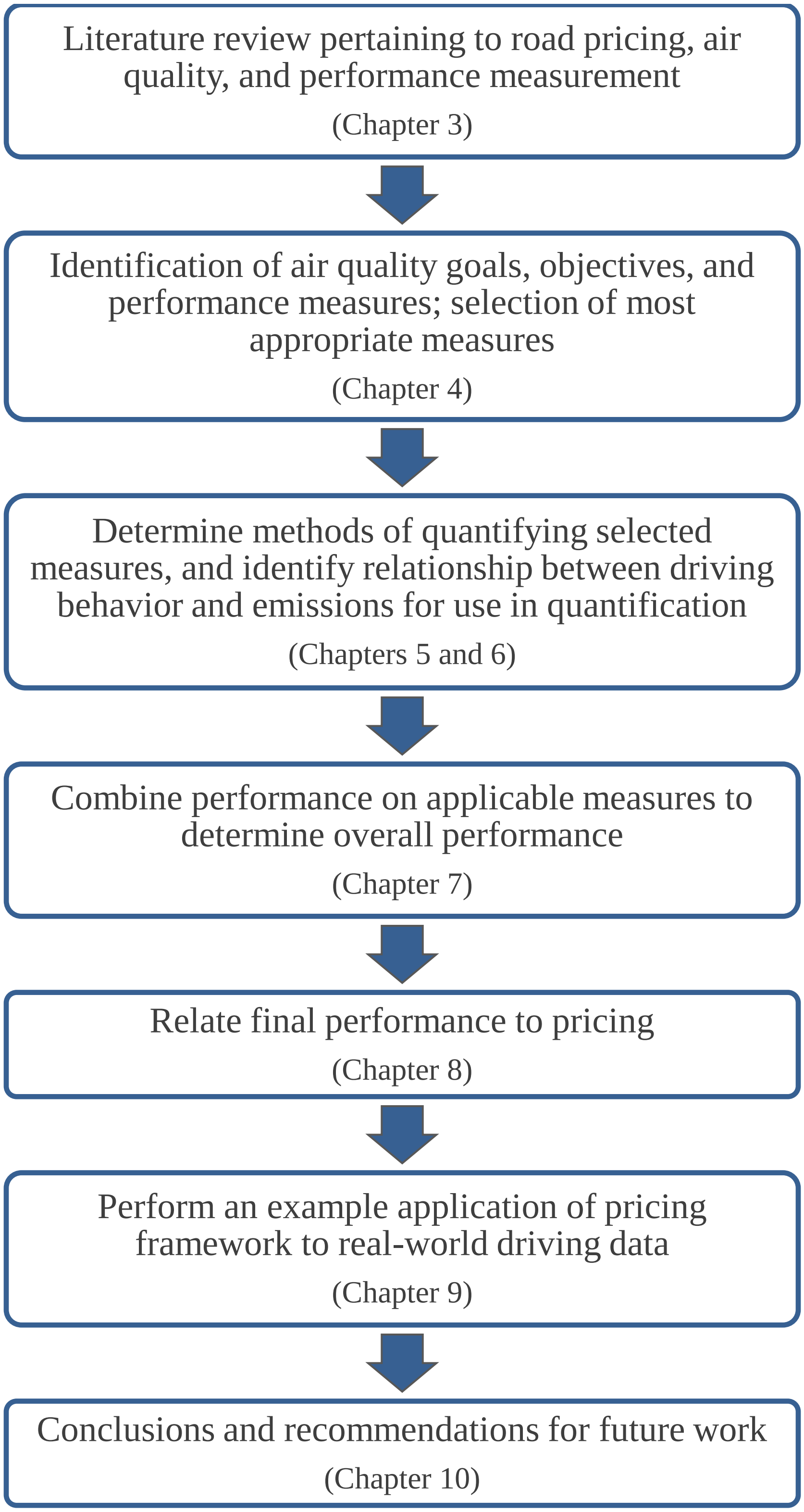


**Figure 3: Project process and location in report.**

In addition to showing the progression of research undertaken for this project, Figure 3 shows the location of each project step within this report. This report discusses, sequentially, the steps taken to develop a pricing framework. In addition, Appendix A includes a list of all acronyms used within the report for reference.

This project is significant in that it represents one of the first steps toward addressing air quality related policy goals through a mileage-based user fee system. MBUFs 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. Mileage-based pricing may also be beneficial to society as a whole to the extent that it can address externalities and social equity. MBUFs could also be prospectively used to internalize costs that are currently external to the user, such as environmental externalities. However, such a use has not been fully addressed in research or pilot programs. Air quality, energy use, and climate change are all current concerns within the transportation industry. The developed methodology for determining a pricing scheme could be used in the future, or provide a basis for similar systems in the real world. Finally, in addition to potential applications of such a system, this research may lead to additional investigation into the uses of mileage-based user fees or identification of future potential research areas.

# CHAPTER 2: LITERATURE REVIEW

## User Fees in Transportation: Pricing Mechanisms

### *The Fuel Tax*

The fuel tax is the most prominent "user fee" in place for the funding of infrastructure development at the state and federal level. The tax is generally assessed on the physical amount of fuel purchased (paid in cents per gallon), although there are states that levy a sales tax on the purchase price of fuel. The current federal fuel tax has been set at 18.4 cents per gallon since 1993 and the diesel tax rate is 22.4 cents per gallon. The Texas state gasoline and diesel taxes have been set at 20 cents a gallon since 1991 (*4, 5*).

While fuel taxes are a proxy fee for use, in that most vehicles using the national highway system will have to purchase fuel for such use, there are many factors undermining the fuel tax's ability to generate revenue in proportion to use. The fact that the fee is fixed to the physical amount purchased, as opposed to the purchase price, means that fuel taxes lose purchasing power over time if not raised to account for inflation and increases in the cost of constructing and maintaining infrastructure. Furthermore, because revenues are tied to fuel consumption, and not actual use, fuel taxes will return less and less revenue as the overall fuel economy of the auto fleet improves.

This particular aspect of the fuel tax is worth further examination, as increases in fleet-wide fuel economy are being driven by two factors that will continue to undermine the tax's ability to provide long-term revenue. The first factor is high fuel prices, which in the short term marginally reduce travel, but in the long term drive consumers to purchase more fuel efficient vehicles. The second factor is federal governmental regulations; namely, Corporate Average Fuel Economy (CAFE) standards that dictate the fuel efficiency of vehicles produced for sale in the United States. The standards have recently been increased by the administration of President Barack Obama, and stipulate that 2016 model vehicles will be required to have an average fuel efficiency of 35.5 miles per gallon (*6*).

### *Use-Based Fees*

While not as ubiquitous as fuel taxes in terms of funding transportation infrastructure in the United States, usage fees in the form of road pricing are becoming much more commonplace domestically and internationally. Pricing in this context can encompass a number of applications, including toll roads, truck fees, and cordon tolling. Most of these applications are smaller in scale than what might be implemented under statewide or national MBUF systems. This is due in large part to the fact that these systems are often implemented in conjunction with the development of added capacity facilities or are applied in smaller, regional settings for the attainment of specific regional goals and objectives. These systems are generally not implemented with the sole objective of generating revenue for infrastructure development and often include policy goals aimed at:

- Reducing congestion;
- Recovering construction and maintenance costs;

- Encouraging shifts to transit and other high occupancy modes; and
- Encouraging the adoption of environmentally friendly technology.

Specific policy goals will tend to vary depending on the type of pricing application and the area being priced. Thus, there is often wide variability in terms of the travel characteristics being metered and priced. The following represent the most common data element gathered in administering, managing and evaluating transportation pricing systems:

- Total distance traveled;
- Time of travel – generally collected for the application of congestion charges or for the enforcement of operating hours (such as in trucking applications);
- Location of travel – can be general or facility specific; and
- Vehicle characteristics such as weight, age, emissions class and axle configurations.

Pricing works to internalize the cost of externalities associated with travel, which in turn discourages low-value trips and encourages more efficient use of the transportation network. Often referred to as marginal cost pricing, these types of systems are often difficult to implement due to:

- Difficulty in accurately determining optimal prices;
- Complexity of road networks;
- Presence of multiple travel modes and time periods;
- Dynamic nature of the required decision making; and
- Interaction with other economic sectors (*7*).

Pricing can also be politically difficult to implement. This is attributable to the fact that users of the domestic roadway network generally perceive that they are currently using infrastructure for free. It is also difficult from a political standpoint because pricing alters the burden of financing the transportation system among classes of users. Furthermore, pricing systems generally require an investment in suitable and reliable technology, which in some cases may prove problematic (7).

**Pricing for the Environment.** While pricing has not been implemented in the U.S. as a means of specifically addressing environmental conditions, environmental components have been incorporated into pricing systems. For example, in 2008 the Colorado Department of Transportation (CDOT) initiated a hybrid vehicle program that permits hybrid owners to utilize the Interstate 25 (I-25) Express Lanes for free and to access High Occupancy Vehicle (HOV) facilities throughout the state. Furthermore, many system management goals simultaneously address environmental goals. For example, comprehensive pricing strategies, such as vehicle miles traveled pricing and pay-as-you-drive (PAYD) insurance, could reduce greenhouse gas emissions in the short term by up to 3 percent or about 75 million metric ton carbon dioxide-equivalent emissions (mmt$CO_2$e). This is due to the fact that while these policies are implemented as a means of generating revenue or managing demand, they have the side effect of reducing the overall number of vehicle trips and reducing emissions. Specific market pricing, such as cordon and intercity tolling, will have smaller overall impact but benefits will be consistent with the size of the area being priced. Congestion pricing, wherein price for access to a given facility or area increases with volume, will reduce VMT and result in more efficient traffic operations. Comprehensive congestion pricing on all roadways could result in benefits of around 1.4 percent of transportation GHG emissions or 35 mmt$CO_2$e.

**Single Facility Congestion Tolling.** In this application, users pay a fee for access to a given facility. If one of the goals of the pricing system is to manage congestion, then it is likely that the fee level will vary depending on the volume of vehicles using the facility. Price for access will increase as volume increases, so as to price smaller value trips off of the facility and maintain a high level of service. The primary policy goal is typically to ensure free flow traffic and maximize capacity. Examples of these types of pricing systems include:

- Toronto 407 Express Toll Route (ETR);
- Orange County State Route 91 (SR-91);
- San Diego Interstate 15 (I-15) high occupancy toll (HOT) lanes;
- Houston I-10 QuickRide;
- Minnesota I-394 MnPASS; and
- Santiago, Chile − Variable tolling on privately financed tolls for quick expansion in road capacity and congestion mitigation.

**Cordon/Area Congestion Tolls.** In a cordon pricing system, users pay a fee to enter and/or travel within a specified charging zone. Most often this priced zone encompasses a central business district (CBD) and the pricing is levied so as to reduce traffic volumes within the cordon. The fee levied for access is generally in place during peak hours.

There are no cordon pricing systems in place within the United States. In 2008, New York Mayor Michael Bloomberg's proposal to charge drivers $8.00 to enter a congestion zone in Manhattan south of 60th Street during peak hours was defeated before it was even introduced in the State Assembly. The highly publicized proposal suffered strong opposition from officials in the areas surrounding Manhattan; namely Queens, Brooklyn and New York's many suburbs, who felt that the measure was regressive and only affluent Manhattan residents would benefit (*8*).

The city/state of Singapore has implemented a cordon pricing system around the central city core. Rates vary by the time of day and are adjusted quarterly. Changes are based on 85th percentile speed (*9*). Net revenues of $75 million were taken in 2008 (*10*). The city's road pricing system has operated since the mid-1970s and "permit auctions" are used to control the rate of growth in vehicle ownership (*11*). This process helps to ensure that the congestion charge does not rise too high and preserves a higher level of service. Singapore's single party leadership has also allowed for a longer term decision making process that has greatly supported the pricing program.

London has implemented a similar system, wherein a charge is levied for entry into the center of the city. The amount paid is a flat, daily fee. A 90-percent discount is provided for residents within the zone, and 30 percent of vehicles are exempt from paying the fee. The performance of the system in achieving its policy goals is measured in numerous ways. Following implementation of the system, the number of vehicles entering the charged area dropped by 25 percent and the amount of circulating traffic was reduced by 15 percent in the first year of operation. Travel speeds increased by 30 percent, trip times decreased by

14 percent, and traffic delays within the charging zone dropped by 25 percent. The system also reduced daily vehicle trips by an estimated 70,000 over a one-year period and it is estimated that 50 to 60 percent of those trips were shifted to transit, 15 to 25 percent shifted to carpooling and 20 to 30 percent of trips were simply eliminated. In 2007 and 2008, the system generated net revenues of $220 million (*10*).

Stockholm, Sweden, has implemented a cordon pricing system around the central city. Drivers wishing to enter the cordoned area are subject to a flat fee. Performance of the pricing mechanism in meeting policy goals is measured in terms of travel time. Since implementation, Stockholm has seen about a 20-percent reduction in traffic. About 30 percent of vehicles in the area are exempt from paying the fee, and a discount is provided to residents living in the Lidingo area of the city, which is adjacent to the priced area. Residents of Lidingo are unable to leave their area without passing through the priced cordon. Hence, the Lidingo rule allows these residents free passage through the charge zone provided that they exit the charge zone within one hour of entering (*10*).

**Weight-Distance Truck Tolls.** These types of fees are generally levied on heavy-duty freight vehicles, which are charged a fee for use of the road system that may vary based on several vehicle characteristics, such as the weight of the vehicle and its emissions class. The fee is generally paid based on the distance traveled, which may be calculated in any number of ways. The primary policy goal is typically to recover costs associated with the operation of heavy-duty vehicles on the road network.

Weight-distance charging for commercial vehicles is utilized in the state of Oregon in lieu of a state diesel tax. Additionally, the states of Kentucky, New Mexico, and New York levy similar weight-distance fees assessed on total miles traveled. Weight-distance charging for commercial vehicles is utilized to a much greater extent and with a higher level of technical complexity in Europe.

The Czech Republic utilizes a truck tolling scheme with a fee that varies based on the type of roadway, weight of the vehicle, number of axles, and emissions class. Vehicles classified as emissions class Euro III-V are assessed a lower distance rate than Euro 0-II vehicles, and vehicles with more axels are assessed a lower rate than vehicles with fewer axles. The average toll rate is equivalent to $0.35 per mile, and the system generated around $350 million in revenues in 2008. Around 40 percent of the vehicles paying the charge are foreign trucks. Furthermore, there are currently laws in place that prohibit truck operations on Sundays and peak times on Friday evening and Saturday morning (*10*).

Germany's truck tolling utilizes a fee structure that also varies based on distance, vehicle type, and emissions class. The fee is applied to vehicles over 12 tons and is only applicable for travel on motorways. The fee amount is structured to recoup direct capital and operating costs imposed on the system by truck traffic. Germany's truck tolling system employs a GPS and a Global System for Mobile Communications (GSM) on-board device (*12*). About 35 percent of vehicles in the system are foreign trucks. The system has performed well in shifting freight to cleaner technologies. Between 2005 and 2009, the percentage of total fleet vehicle miles logged by cleaner Euro IV and Euro V class vehicles rose from 2 percent to nearly 62 percent, while the percentage of vehicle miles logged by dirtier Euro I, Euro II and Euro III vehicles dropped from 98 percent to 38 percent (*12*).

The Slovak Republic employs a truck tolling system that covers motorways, expressways and select 1st class roads. Fee amounts vary based on the category of the roadway and vehicle class (defined by number of axles and emissions class), but the primary policy objective of the system is to generate funding for infrastructure development. The fees apply to domestic and foreign vehicles with a maximum laden weight above 3.5 tons. Fees are assessed through the use of self-installed equipment (*13*).

Switzerland employs a Heavy Vehicle Fee (HVF) that applies to all vehicles with a maximum laden weight in excess of 3.5 tons. The fee is calculated based on the distance driven on all Swiss roads, the weight of the vehicle and the emissions class of the vehicle. The system employs a GPS and Dedicated Short Range Communications (DSRC) equipped on-board unit that ties directly into the vehicle's tachometer. The system was initially implemented out of a concern for increased foreign freight movement and a high level of concern for mitigating the environmental impact of freight movement (*14*).

In Austria, the GO Maut heavy goods vehicle (HGV) tolling system applies a distance-based charge to all vehicles exceeding a maximum admissible weight of 3.5 tons. Fee levels vary based on weight class and the number of axles. This system was implemented to address the expense of road maintenance due to increasing foreign freight movement. Participating vehicles utilize a DSRC-equipped on-board unit that communicates with over 420 roadside gantries. The private sector plays a substantial role in infrastructure development and maintenance (*15*).

**Distance-Based User Fees.** Fuel taxes have traditionally provided the bulk of funding for surface transportation programs at both the state and federal levels. However, the increasing fuel efficiency of the U.S. auto fleet, driven by high fuel prices and various governmental mandates regarding future fuel economy, is undermining the ability of fuel taxes to provide sustainable funding in the long term. This is due to the fact that these factors actively encourage a reduction in fuel consumption relative to actual travel, which will result in decreasing fuel consumption over time even as overall travel increases. Furthermore, as alternative fuel vehicles gain greater and greater market penetration, there will eventually develop a potentially large segment of the auto fleet that falls outside of the traditional fuel tax collection framework.

Many have called for the study and eventual implementation of a distance-based replacement to the fuel tax. Such a mechanism has been referred to by many different names:

- Vehicle Miles Traveled fees;
- Vehicle Mileage (VM) fees;
- Mileage-Based User Fees;
- Time-Distance-Place (TDP) charging; or
- Simply mileage fees.

Regardless of the name this replacement mechanism is developed and implemented under, the basic underlying theory is that road users would pay directly for their use of roadway resources by paying a fee on the mileage driven as opposed to the fuel consumed. These fees have been recommended for further study and evaluation by the:

- Transportation Research Board (TRB) (*16*);
- National Surface Transportation Infrastructure Financing Commission (*17*);
- National Surface Transportation Policy and Revenue Study Commission (*18*);
- Bipartisan Policy Center (*19*); and the
- American Association of State Highway and Transportation Officials (AASHTO) (*20*).

Like weight-distance fees, these types of fees are assessed on the distance traveled, but are applied to passenger vehicles as well as commercial vehicles. Users are charged a fee for road use that is assessed based on the distance traveled so that as travel increases, the amount due increases. Price may vary based on any number of factors. The primary policy goal will generally be long-term transportation-related funding and financing, but other policy goals can be incorporated into the pricing system.

Domestically, there are currently no distance-based user fee systems in place outside of Oregon's weight-distance tax on commercial vehicles. Oregon, in fact, was the first state to test a distance-based fee system for passenger vehicles. Launched in 2006, Oregon's Road User Fee Pilot Study equipped vehicles with an on-board unit that recorded mileage driven within specified zones. These units utilized GPS signals to determine what zone the vehicle was in and allocated mileage to that zone. A map of these zones was contained in a geographic information system (GIS) file within the unit itself. Mileage was counted through a connection to the odometer. Mileage totals were transmitted to a billing center whenever a study participant would fuel their vehicle at a participating service station and the mileage fee amount was applied to their fuel purchase. This fee was applied as a credit to the fuel taxes paid in order to prevent double payment of road usage taxes. Over 90 percent of the study participants stated they would agree to continue paying the mileage fee in lieu of the gas tax if the program were extended statewide (*21*).

A distance-based charging system was also tested in the Puget Sound region of Washington State, although the aim of the study was to evaluate behavioral changes in response to tolling as opposed to testing a replacement for the fuel tax. Using only incentives (meaning, participants could earn cash by reducing travel as valued by the program), this experiment aimed to determine the feasibility of using GPS-based on-board units (OBUs) with a cellular-based transmission system to levy tolls for the use of area roadways. The principal focus of the study was to reduce vehicular trips and maintain a high level of public acceptance. Transportation finance was not a main consideration in the experiment. The results of the study showed that participants had reduced their travel in a manner that, if aggregated across the whole Puget Sound Region, would have a "major effect on transportation system performance." It was calculated that the present value of the net benefits generated by the system over a 30-year period would be $28 billion (*22*).

The University of Iowa is currently conducting a national evaluation of technological and pricing options for a potential VMT-based fee. The system being tested by researchers utilizes on-board receivers that work in conjunction with GPS satellite technology to determine each vehicle's location in relation to GIS files stored in the on-board unit. A price per mile is then affixed to each particular trip. This price per mile is applied to the number of miles traveled as provided by the vehicle's odometer, with price changes occurring whenever the GPS system indicates that the vehicle has entered into an area with a different per mile price or into a new jurisdiction. Data stored in the on-board unit will be uploaded via cellular technology to a billing and dispersal center on a pre-programmed schedule (*23*).

**Distance-Based Price Variabilization.** While this is not a true user fee, in that it is not generally implemented by governmental entities to generate revenue, variabilizing certain costs can be implemented as a means of producing transportation-related policy results. Generally, cost variabilization involves making traditionally static vehicle ownership and usage costs variable. One recently developed example is PAYD insurance, which replaces the traditional premium based payment of vehicle insurance with a system that allows the user to pay insurance on a per-mile basis. The basic theory behind this application is that variabilizing certain fixed costs will enable users to save money by modifying their travel behavior in a way that maximizes their own utility. Congestion reduction and associated environmental effects are generally expected to occur as a result of these pricing systems.

## User Fee System Goals and Objectives

Mileage fees are viewed as a desirable replacement mechanism for the fuel tax for reasons other than their potential to generate long-term revenue. Depending on how they are structured, in terms of how they are calculated and how they are administered, they can be implemented to attain a number of policy goals.

It is important to ensure that any discussion of potential mileage fee implementation begins with a thorough assessment, statement, and prioritization of policy goals. This is necessary because the configuration of the system itself will affect what goals can be reasonably attained by the system. For example, implementation of pricing policies that require the collection of detailed travel information, such as a congestion pricing element, might impede the ability to insure absolute driver privacy.

Effective and comprehensive road pricing systems are dependent on clearly defined and well understood policy goals. For example, Singapore employs a master transportation plan that addresses how to integrate road pricing with transit, expansion of roads, and land use issues. The London and Stockholm pricing systems' policy goals guided other decisions such as use of revenues, rate schedule, and exemptions. Germany's truck charging system's primary purpose is to generate revenues, but it also has secondary objectives related to shifting freight to alternative modes such as rail and waterways. Modal shift can be accomplished by allocating revenues generated by the system to enhancements in alternative modes. For example, it is fairly routine for urban road pricing applications to dedicate portions of the revenue they generate to transit enhancement. However, with regard to truck pricing systems, the allocation of revenues generated by users to other transportation modes have, in the past, undermined prior commitments to truckers. The German truck tolling system must, therefore, strike a balance between returning revenues to the system from which they are generated and allocating revenues for the enhancement of other modes. Currently, 50 percent of toll revenue is returned to roadways, 38 percent is allocated to rail, and 12 percent is allocated to inland waterways (*10*).

In general, mileage-based fees can be implemented to attain two main policy goals: revenue generation and system management.

*Revenue Generation*

Mileage-based user fees are at the most basic level generators of revenue, and long-term revenue generation has generally been the primary motivation for domestic MBUF evaluation efforts. However, revenue goals may be articulated in more specific terms, such as:

- Replacing an existing revenue source such as fuel taxes or vehicle registration fees;
- Supplementing existing transportation revenue mechanisms;
- Generating revenue on an area specific basis, such as by jurisdiction; and
- Generating revenue on a facility specific basis.

Finely articulated revenue objectives will have different implications for system design. A fee system oriented around collection of revenues on an area specific basis will likely require some level of location information for proper assessment. Furthermore, a system oriented around generation of facility specific revenue will require more detailed location information and perhaps even time of day information for the application of congestion pricing. The Oregon pilot (*21*) and University of Iowa demonstration (*23*) were both concerned with generating revenues on an area specific basis. In-vehicle units only needed to know that they were in a certain city, county, state or country. This level of detail would have been insufficient to carry out the facility specific pricing application tested in the Puget Sound Region.

An MBUF system implemented with the objective of replacing the fuel tax will have to be structured from an assessment and administration standpoint such that drivers will not have to pay both the MBUF and the fuel tax—a far different architecture than what would be required for an MBUF implemented as a supplemental revenue source.

*Capture of User Costs*

A fundamental basis for efficient road pricing is that the charge for use should accurately capture the various costs associated with that use. Thus, outside of revenue generation, a policy objective of an efficient road pricing system is likely to be that of capturing the costs imposed on the roadway by users. In practical terms, this means that revenues generated by the system should be sufficient to cover the costs to maintain, operate and, in some cases, develop the facilities composing the charged network.

Assessing use within a road pricing context requires the articulation of what constitutes a cost. The most basic element of cost used in road pricing is that of wear and tear on the roadway system. In general, heavier vehicles, and particularly heavy-duty vehicles with insufficient load distribution, cause significantly greater wear and tear on roadway surfaces. Thus, most domestic and international truck tolling systems vary distance rates such that lighter vehicles and vehicles with more axles (and thus better load distribution) are assessed a lower rate. Implementing a system that properly accounts for the costs associated with wear and tear could be facilitated by an assessment of the impact of individual vehicle types on the roadway network. The fee system could also be structured to account for the varying cost of maintaining and operating different facility types. Many European truck tolling systems charge increased distance rates on higher quality facilities.

Expanding the definition of costs beyond wear and tear will likely complicate the pricing system. For example, the cost of congestion is a factor that might be considered for inclusion in a mileage-based user fee pricing system. In terms of deployment, this would mean collecting information on time of travel and specific location of travel. However, congestion pricing is viewed as a potentially useful application with regard to mileage-based user fee systems.

*System Management*

Fee systems with system management oriented objectives seek to influence how drivers utilize roadway resources. The specific objectives associated with such a system might include:

- Reducing congestion;
- Reducing traffic volumes;
- Reducing travel demand;
- Optimizing capacity;
- Increasing vehicle speeds;
- Improving user access to the transportation network;
- Inducing modal shift to transit, rail or some other alternative; and
- Restricting unnecessary vehicle access.

Pricing systems with system management oriented objectives might, and often do, incorporate congestion pricing or a value pricing element, where fees for access to infrastructure increase as volume increases. This is done in order to mitigate the effects of traffic congestion by shifting travelers to other modes of travel, other times of travel, less-congested facilities, or even cancel trips in order to increase overall throughput. In the United States, such pricing systems are often found in HOT lanes, where excess capacity on HOV lanes is priced to allow utilization by single occupant vehicles (SOVs). System management objectives are also found in international pricing applications such as London, Stockholm, and Singapore; although these systems are not dynamic in nature, meaning that fees do not vary based on real time traffic conditions and fluctuate on a predefined schedule. System management objectives are generally adopted for smaller scale pricing systems, such as those that incorporate a few facilities or cover a small geographic area.

Fee systems with system management objectives generally utilize some form of technology, either in the form of in-vehicle transponders, roadside mounted technology, or both. This is necessary to determine what vehicles are utilizing the transportation system, as these types of objectives are not commonly applied over large areas. Technology is therefore not necessary in all vehicles. Only the specific facilities subject to the system management fee and the vehicles utilizing those facilities would need to be equipped.

*Environmental Goals*

The use of pricing to achieve policy objectives related to environmental quality is an increasingly common practice in European pricing systems, but is not a major aspect of domestic pricing systems. In general, systems oriented around environmental goals seek to affect air quality within the priced area, be it local or national. System management oriented goals, in as much that they can reduce congestion and resultant emissions, help to achieve environmental related objectives in and of themselves. The Stockholm cordon pricing system has, for example, resulted in a 10- to 14-percent decrease of emissions and a 2- to 10-percent improvement in air quality since deployment. But outside of system management strategies there are also additional methods for explicitly addressing environmental objectives.

A common strategy in local pricing applications is to provide preferences to higher occupancy vehicles that reduce emissions by reducing vehicle trips, namely transit and carpooling. Cordon systems in Stockholm, London and Singapore provide free access to charged areas for transit vehicles. Funding may also be allocated for facility improvements aimed at increasing the attractiveness of transit to potential users. In 2008, over 82 percent of the revenues generated by London's congestion charge were allocated to transit improvements (*10*).

Another common strategy is to price vehicles based on their emissions. Many European truck tolling systems apply a lower distance rate to lower polluting vehicles relative to higher polluting vehicles. Variable pricing based on emissions class in the German truck tolling system has resulted in a 58-percent shift from "dirtier" (Euro Class I, II, III) to "cleaner" trucks (Euro Class IV, V) (*10*). In the United States, vehicle registration fees often vary based on the year of the vehicle, such that older and more polluting vehicles are assessed a higher registration fee.

**Technology Issues**

Mileage fees may be implemented in numerous different forms and rely on of a wide array of technologies. Although most pilot studies and existing systems have relied on a mix of various technology options, mileage fees can also be implemented with no technology requirement. For example, a simple odometer reading can be instituted if the only policy goal for the system is to generate revenue.

There are three basic technological elements of a mileage-based user fee system, which will hereafter be referred to as the *logical architecture*. The logical architecture is composed of three stages: road use assessment, charge computation, and vehicle to back office communications.

*Road Use Assessment*

Road use assessment is the stage in the logical architecture during which raw data describing vehicular movement is collected. There are numerous options for roadway use assessment and each represents a tradeoff between technical simplicity and the level of road use detail obtained. Policy objectives will determine the level of data collection required.

Simple odometer readings are the easiest way of determining how much travel has occurred. These readings provide direct, reliable, and high accuracy distance measurement. The significant drawback of odometer distance measurement is a lack of information on which roadways were used and when miles were driven. The resulting inability to match the fee to the magnitude of cost imposed on the roadway system (i.e., difference in social cost of driving by facility used and time of day) means that full economic efficiency is not attained and that drivers might be charged for mileage accrued outside of the implementing jurisdiction.

Vehicle speed-based distance measurement is another method by which roadway use may be assessed. This would occur through a connection with the vehicle's on-board diagnostic port and entails feeding a detailed record of vehicle starts, stops, and speeds collected at time intervals during each trip into a distance computation algorithm. The distance computation algorithm then provides trip distances. As in an odometer reading-based assessment system, this method does not generate location information, and therefore makes it more problematic for determining out-of-jurisdiction mileage; however, there are methods for accounting for this. Furthermore, there is no standard OBD design, meaning that it would be difficult to manufacture one standard unit for all users participating in the system.

To account for the inability of vehicle speed-based distance measurement to account for where mileage is occurring, an implementing entity might employ beacon-based location-stamping. In this technology configuration, a location stamp would be applied to road usage data through the use of roadside beacons. However, this configuration would require a network of location-marking beacons that have distinct locations, cover the entire roadway network, and maintain a constant line of communication with vehicles.

The most high-tech method for evaluating road usage would involve detailed time and location-stamping. In this configuration, a wide-area communications technology would be used to continuously broadcast sets of location coordinates to vehicle OBUs. The vehicle OBUs would then triangulate from these coordinates to determine the location of the vehicle. Vehicle location coordinates could then be matched to a network map to determine specific network use, and a complete record of vehicle movement could be generated. GPS technology is among the most prominent candidates for this type of assessment technology.

*Charge Computation*

During the charge computation stage, data gathered during road usage assessment is processed to determine an amount owed. There are two main assessment configurations: "thin" client and "thick" client.

In a "thin" client configuration, aggregated travel data are transmitted out of the vehicle and processed at another location, whereas in a "thick" client configuration, the charge computation occurs within the vehicle OBU. This distinction is important, because each configuration has unique advantages and disadvantages. "Thin" configurations would require a simpler on-board unit that could be more easily updated as jurisdictional boundaries and fee schedules change. Furthermore, due to the fact that aggregate travel data are being transmitted, "thin" configurations will enable easier auditing by users. Conversely, "thick" client configurations will better safeguard driver privacy due to the fact that very little information is transmitted out of the vehicle. However, OBUs will be much more difficult to update, impeding system flexibility, and will not allow for the provision of various value added services that rely on detailed information regarding vehicular movement. European Union (EU) regulations related to privacy have resulted in most European truck tolling systems utilizing a thick client approach.

Third parties may play a role in data management and charge computation, and can be employed in either configuration to address various deficiencies. For example, a private third party might act as a "privacy shield" under a "thin" client configuration, handling the raw data before it is transmitted to a governmental entity for billing purposes.

*Vehicle to Back Office Communications*

This is the final stage in the logical architecture, and entails the transmission of data for the computation of the amount owed or the transmission of the already-computed amount owed from the vehicle to a back office. The most low-tech option for this process would entail a manual reading of the odometer.

A more technology intensive option would be to utilize a localized, detection-based transmission system. DSRC technology, for example, has been used for weight-distance truck highway tolls. DSRC-based pricing systems; however, would require the placement of a network of roadside readers, which might be cost prohibitive in a wide area charging system.

Another option would be to utilize a wide area, constantly online data transmission system, where area-wide data transmission (that did not relay on individual readers) would be used to download data from vehicles within a large radius and forward the data to a back office. The GSM system might be utilized for just such a configuration. The Slovak Republic currently utilizes GSM communications for transmitting fee information in its truck tolling system (*13*).

**Institutional Issues**

There are numerous issues facing a potential deployment of mileage-based user fees in the United States.

*Public Acceptance*

Among the most pressing is the issue of public acceptance. There are numerous public acceptance issues, but most can be classified as dealing either with privacy, administration, enforcement or equity.

The most successful European systems in terms of public support have generally been successful due to simplicity in terms of policy goals, messages, business rules and technology solutions. Officials in Stockholm understood that having a pricing system that was easy to understand was essential in maintaining public support. Thus, the Stockholm cordon pricing system that was implemented was as simplified, from an assessment position, as possible (*10*). It utilized a single charge cordon that had the same rate at all points of entry, regardless of the direction of travel, and regardless of whether a trip occurred during the morning or evening peak. The London system is structured such that drivers are charged a flat fee per day of use; regardless of how many times the cordon is crossed within that one day (*10*).

Privacy is perhaps the most dominant public concern, as the public tends to associate a vehicle mileage fee with the notion of being "tracked." Furthermore, there are strong public concerns about information security. Fuel taxes are easy to pay, cheap to collect, and perhaps most important, anonymous. If vehicle mileage fees are to gain a high level of public acceptance, systems for the security of information and privacy protection must be demonstrated. Some potential strategies for addressing privacy concerns include:

- Not allowing the collection of more data than needed for the primary purpose of the system;
- Clearly articulating the level of accuracy expected from data collection tools;
- Clearly stating when data are to be collected and for what they are to be used;
- Refraining from using data for new purposes without consent;
- Ensuring data are safe and secure, and that only needed data are retained;
- Allowing users the opportunity to correct faulty data; and
- Proactively supporting the above principles (*24*).

Privacy issues can be addressed through on-board data aggregation, as would occur in a "thick" client configuration. Travel data are aggregated and charge computation occurs within the on-board equipment, reducing the need to communicate detailed travel data outside of the vehicle.

Third party privacy agreements can also be utilized to address privacy concerns. Aggregated travel data can be transmitted to a trusted third party that is obligated to keep these data private. This third party can either: 1) calculate the total amount due and then transmit this amount to the governmental entity; or 2) make the travel information anonymous and forward it on to the governmental entity.

In the study of mileage-based user fees Oregon helped protect driver privacy by establishing a "zone" based system (*21*). Only general location data were required to determine in what zone the driver was located. This allowed for accurate in-state mileage to be calculated without the need for specific trip data.

The on-board units utilized in the University of Iowa's road user-fee assessment study only retain location data for the minimal time necessary to calculate fee charges (*23*). All charges are computed within the vehicle itself, and only the aggregated mileage charges are transmitted to the network operation center. It is impossible for the system to "track" participants.

*Equity*

Equity issues are also likely to be prominent in the development of mileage-based user fees. Domestically, these issues have generally been expressed in terms of the fees' effect on low income groups and on rural drivers.

Equity concerns can be addressed in many ways. The first is through the use of exemptions. For example, Stockholm's Lidingo rule helped build support for the system by allowing those who could not avoid the charge zone a free trip provided that they exited the zone within a certain period of time. Similarly, Central London residents are provided a 90-percent discount on their trips within the charge zone (*10*).

Equity issues might also be addressed through the allocation of revenue. Revenues from the London, Stockholm, Singapore, and Netherlands pricing systems are used to fund other modal options that lower income residents are more likely to use (*10*). In Singapore, surplus revenue is refunded to vehicle taxpayers.

Equity issues might also be addressed by directly linking the price paid to benefits received. For example, Sweden sets bridge toll rates so as to reflect the benefit of using these priced facilities as opposed to free alternatives (*10*). Germany administers a mitigation fund that truckers may use for training and equipment upgrades (*12*).

**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 vehicle specific and system-wide factors that influence emissions that can then be efficiently priced to achieve desired objectives.

*Background on Air Quality and Emissions*

Air quality is an increasingly important concern both nationally and worldwide. Air quality consideration is no longer limited to the six criteria pollutants covered by the National Ambient Air Quality Standards. Now, in addition to carbon monoxide (CO), lead (Pb), nitrogen dioxide ($NO_2$), ozone ($O_3$), sulfur dioxide ($SO_2$), and particulate matter (PM); air toxics and greenhouse gases are cause for concern as well (1). The United States EPA has identified twelve major sources of emissions:

1. Fertilizer and livestock;
2. Electricity generation;
3. Fossil fuel combustion;
4. Residential wood combustion;
5. Waste disposal;
6. Fires;
7. Industrial processes;
8. On-road vehicles;
9. Non-road equipment;
10. Road dust;
11. Solvent use; and
12. Other miscellaneous sources such as construction and gas stations (*25*).

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). 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 of global-level concern (*26*).

On a positive note, total emissions have stabilized or decreased significantly in terms of absolute numbers, even though the consumption of fuel by various transportation modes has increased from 92.3 billion gallons in 1970 to 128.6 billion gallons in 1991 (*27*). Regulations on internal combustion engine technology, such as the dissemination of the catalytic converter, have resulted in vehicles that emit fewer pollutants than in the past. Vehicle fuel efficiency has also improved. Lead emissions have experienced the most change, resulting from the widespread ban in most developed countries on the use of lead tetraethyl as an anti-knock agent during the 1980s (*27*). However, the number of vehicles on the road continues to grow, and the emission of carbon dioxide ($CO_2$) increases proportionally with transportation usage. $CO_2$ is a greenhouse gas believed to contribute to global climate change. In addition, road congestion does not appear to be improving, and congestion adds to emissions. A study conducted by the Texas Department of Transportation (TxDOT) in Houston found that there was a slight increase in emissions due to nonrecurring congestion caused by traffic crashes (*28*).

There are a number of influential factors to consider when determining the prevailing air pollutant concentration at ground level for an individual source, including:

1. The emission rate, which is linearly related to concentration;
2. The height of emission, as concentrations are less for the same emission rate at a higher altitude because the emissions are more dispersed by the atmosphere;
3. Site topography, since concentration tends to be worse in places where emissions can accumulate, such as street canyons and valleys;
4. Meteorological factors, including:
    a. Horizontal wind speed, which is inversely proportional to concentration;
    b. Vertical mixing (high concentrations develop when they become trapped in a relatively shallow layer of atmosphere); and
5. Removal processes (sinks) such as removal by rain, uptake by land surfaces (including ocean), and removal by atmospheric chemical reaction (*29*).

In other words, air quality is influenced by more than just a vehicle's emission rate and the miles traveled. The most accurate model of air quality, therefore, should account for as many factors as possible.

*Significance of Transportation – Mobile Source Emissions*

The criteria pollutants addressed by the EPA include CO, Pb, $NO_2$, $O_3$, $SO_2$, 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 between 10 and 2.5 micrometers ($PM_{10}$) (*30*). Ozone is not directly emitted and is typically formed from a chemical reaction between nitrogen oxides (NOx), volatile organic compounds (VOCs), and sunlight.

Aside from their relationship with ozone, volatile organic compounds are also a problem on their own merit. VOCs are the gaseous form of hydrocarbons (HCs), and are common groundwater contaminants. These compounds typically have a high vapor pressure and low water solubility. Many are human-made chemicals, including industrial solvents such as trichloroethylene, and fuel oxygenates such as methyl tert-butyl ether (MTBE) (*31*). VOCs are a problem in the transportation field because they are often a component of petroleum fuels, and are emitted both through the incomplete combustion of gasoline and as a byproduct of the petrochemical industry (*32*). As such, VOCs should be given consideration in any air quality analysis. Additionally, all NOx should be considered, rather than just $NO_2$. In fact, the pollutants of greatest concern for Texas are NOx, VOCs, and ground level ozone (formed when NOx and VOCs react on hot, sunny days) (*33*).

Other problematic emissions include mobile source air toxics (MSATs) and chlorofluorocarbons (CFCs), which result primarily from vehicle air conditioning. 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 (*34*). Although there are no NAAQS for MSATs, in 2001 the EPA identified six out of 21 MSATs that have the greatest health impact (*35*). These include the known carcinogen benzene, and potential carcinogens 1,3-butadiene, formaldehyde, acrolein, acetaldehyde, and diesel particulate matter (DPM). Benzene is emitted in unburned fuel or as vapor when gasoline evaporates, while the others are byproducts of incomplete combustion or chemical reactions. This list of 21 compounds was eliminated in 2007 in favor of a more flexible approach, where toxics considered a key MSAT may change over time. Currently, there are 93 compounds documented in the EPA Integrated Risk Information System (IRIS) database. As of 2008, the key MSATs included the six listed above, as well as naphthalene and polycyclic organic matter (POM) (*36*). VOCs are also considered MSATs. Emissions of MSATs can be reduced through emission reductions of VOC, PM, and diesel emissions (*30*).

All of these pollutants pose a serious risk to both the environment and public health. People that live very near a highway, railroad, or airport are especially at risk, because concentrations of hazardous air pollutants increase significantly the closer one gets to these sources (*30*). Tables summarizing information on some of the major pollutants are located in Appendix B. Information includes potential health effects and environmental effects. A table is also included that summarizes aspects of some environmental consequences of air pollution—smog, acid rain, and odors.

Of increasing importance is consideration of GHGs, which are atmospheric gases that absorb and emit infrared radiation—the basic cause of the greenhouse effect. The greenhouse effect is a process where heat from the sun is trapped by the atmosphere, which allows the planet to support life. However, an increase in $CO_2$ and other GHGs in the atmosphere is believed to increase the trapping of infrared radiation and thereby lead to a rise in global temperatures. 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 (*37*). 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 (*38*). Within transportation, about 66 percent results from gasoline combustion, 16 percent from diesel, and 15 percent from jet fuel (*25*). Additional information on $CO_2$ is also included in Appendix B.

*Current Air Quality Legislation and Transportation Conformity*

The first federal legislation related to 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 (*39*). Under the Clean Air Act (CAA) of 1970, 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.) (*40*). These national ambient air quality standards for the six criteria pollutants are shown below in Table 2 (*41*).

**Table 2: Current National Ambient Air Quality Standards**

| Pollutant | Emission Level | Averaging Time | Primary/ Secondary | Form |
|---|---|---|---|---|
| Carbon Monoxide | 9 ppm | 8-hour | Primary | Not to be exceeded more than once per year |
| | 35 ppm | 1-hour | | |
| Lead | 0.15 μg/m$^3$ | Rolling 3-Month Average | Primary and Secondary | Not to be exceeded |
| Nitrogen Dioxide | 100 ppb | 1-hour | Primary | 98$^{th}$ percentile, averaged over 3 years |
| | 53 ppb | Annual | Primary and Secondary | Annual Mean |
| Particulate Matter ($PM_{10}$) | 150 μg/m$^3$ | 24-hour | Primary and Secondary | Not to be exceeded more than once per year on average over 3 years |
| Particulate Matter ($PM_{2.5}$) | 15.0 μg/m$^3$ | Annual | Primary and Secondary | Annual mean, averaged over 3 years |
| | 35 μg/m$^3$ | 24-hour | | 98$^{th}$ percentile, averaged over 3 years |
| Ozone | 0.075 ppm | 8-hour | Primary and Secondary | Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years |
| Sulfur Dioxide | 75 ppb | 1-hour | Primary | 99$^{th}$ percentile of 1-hour daily maximum concentrations, averaged over 3 years |
| | 0.5 ppm | 3-hour | Secondary | Not to be exceeded more than once per year |
| *where ppm is parts per million, μg/m$^3$ is micrograms per meter cubed, and ppb is parts per billion | | | | |

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 (*42*). These pollutants may be damaging to property, in addition to health and the environment. The EPA must review the latest scientific information and standards every five years, and make changes as needed (*43*). 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, and generally includes:

1. A monitoring program—to measure actual concentration of the pollutant and determine if an area is compliant with standards;
2. Air quality calculations and computer modeling—to predict future trends and the effects of emissions reduction strategies;
3. Emissions inventories—to describe the sources and categories of emissions to the air for a given pollutant, and how much they emit;
4. Control strategy studies—to find the best way to reduce emissions in order to meet standards;
5. Formal adoption of measures to achieve necessary reductions; and
6. Periodic review to evaluate whether reductions were achieved in reality, and whether they had the predicted result (*44*).

If the EPA does not approve the SIP, they can issue and enforce a Federal Implementation Plan (FIP). There are also penalties (“sanctions”) that the EPA can impose on areas that do not satisfy the SIP requirements (*44*). The areas must attain standards by specific dates. Some areas choose to enter into an Early Action Compact (EAC) with the EPA, in order to have the flexibility to develop their own air pollution control strategies. The goal is that EAC areas will begin reducing air pollution about two years earlier than they would have otherwise. The incentive for these communities is that penalties associated with nonattainment designation will be deferred, as long as agreed upon milestones are met (*45*).

*Vehicle Emission Estimation*

In order to quantify emissions and develop performance measures, appropriate sources of data must be obtained. Regional air quality management districts typically collect information on air quality and pollution. The data collected should not be limited to only VMT. For example, measurement of $CO_2$ typically involves vehicle mileage and speed figures, as well as assumptions regarding average fleet fuel efficiency. However, in collecting data local authorities may exclude mileage on state or interstate facilities, and are unlikely to know exact fuel efficiency (*46*). Thus, results may not be entirely accurate, and depend on assumptions made in data collection. Furthermore, discrepancies may arise from modeling rather than measuring emissions. For modeling, passenger vehicles and heavy-duty vehicles should be considered separately if possible. Different vehicle types have different emission rates, and may travel at completely different speeds due to different typical driver behavior (*47*). 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/restart (*48*).

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 (AVI) can provide fairly disaggregated VMT and speed data, as it tracks individual vehicles over time, potentially through the use of infrared scanners at tolling facilities. GPS can also provide significant travel information, including second-by-second speed and location. In addition, 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, $CO_2$, nitric oxide (NO), oxygen molecules ($O_2$), and PM smaller than 1-2.5 microns, and can calculate NOx from the NO emissions (*49*).

As an alternative to directly measuring emissions, emissions data may be produced through computer modeling and simulation. The public resource TRANSIMS (TRansportation ANalysis SIMulation System) can model speed and VMT data for different vehicle classes, although data are more aggregated than if AVI were used. The Texas Transportation Institute (TTI) has developed a method for selecting an appropriate vehicle mix for use in modeling, to best reflect actual conditions (*50*). The MOBILE emission modeling software, first developed by the EPA in 1978, is used significantly 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 (*51*). 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 (*52*). The most recent version, MOBILE6, offers improved estimates, as it is based on new data, new understanding of the vehicle emission process, and includes the effect of recent regulation (*52*). For example, it includes emissions from air conditioning use and high acceleration, as well as corrections for current fuel content. Emissions estimates can be produced for 28 different vehicle types, as well as for freeways, arterials, local roads, and freeway on- and off-ramps. However, MOBILE6 is limited to speeds below 65 mph, even though speeds may be much higher on freeways and toll roads, which limits its estimation ability (*53*). The most recent update, MOBILE6.2, includes estimation of PM, although it does not have the ability to estimate re-entrained road dust that results from motor vehicle activity. It does include emissions from exhaust, brake wear, and tire wear. MOBILE6.2 replaces the PART5 model (*52*).

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 (*54*). In addition to pollutants modeled by previous systems, MOVES2010 estimates the following MSATs: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, naphthalene, ethanol, and MTBE. There are also some changes to the modeling approach used to estimate mobile source emissions, based on recommendations from the National Academy of Sciences (*55*). The emission calculations are based on 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 (*53*). Preliminary comparison of MOVES2010 to MOBILE6.2 shows that the estimations of VOC were lower with MOVES, especially for Tier 1 and newer vehicles; the estimations of NOx were higher for light- and heavy-duty trucks; and the estimation of $PM_{2.5}$ was significantly higher for light- and heavy-duty trucks within all urban areas modeled.

## 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" that may address processes, outputs, or outcomes (*56*). The terms 'performance measure' and 'performance indicator' are often used interchangeably in literature, or are attributed conflicting meanings. Alternatively, 'indicators' are considered as aspects of performance desired for study, while 'measures' attempt to quantify and evaluate these performance indicators. In other words, "a performance measure is composed of a number and a unit of measure" (*57*). In this way, a measure gives magnitude to the indicator, as well as meaning through a unit of measure. Often, the measure may be presented as a ratio of two different units, such as miles per gallon. In this report, the term 'performance measure' will be primarily used in order to avoid confusion.

Collecting performance information is fairly pointless unless the information is actually used—as in a system of performance management. Performance objectives should be established based on the agency's (or program's) mission and goals. Performance indicators can then be selected to aid in achievement of an objective by identifying and focusing attention on factors that can give an *indication* of performance relative to the objective. Performance measures are then used to quantify exactly how good (or bad) the performance actually was. To aid in this evaluation, performance targets can be established. Thus, the indicators themselves should be qualitative rather than quantitative to remain relevant over time, while the numerical targets for measures can change over time.

### *Background on Performance Measurement*

Performance measurement can improve agency accountability, improve resource allocation efficiency, give an opportunity to advocate for a change, and is recognized in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) as a critical part of long-range planning for transportation (*58*). Agencies can track their progress and monitor quality, as well as system operations. Performance measurement has been used by public agencies for many years, but is now becoming increasingly important, especially as citizens demand accountability and transparency.

Performance measures used by public agencies typically related only to areas directly under the agency's control. For a transportation agency, that might traditionally include capacity, bridge condition, and pavement quality. However, these days various factors contribute to transportation decisions, including water quality, air quality, ecology, economic development, historic preservation, and quality of life (1). Although transportation is not the only factor that affects these areas, and efforts undertaken by other agencies may overlap with the programs of the transportation agency, these issues cannot be ignored. Unfortunately, performance measurement of these areas is more complex, since many environmental and social issues are difficult to quantify.

Many factors must be considered before implementing a performance measurement program. What to measure typically depends on who the users are (managers versus external stakeholders, etc.). In addition, performance is usually considered less about past actions or achievements and more about obtaining objectives in the future. In other words, success cannot just be based on whether or not the agency acted on a certain problem, but whether progress was made toward a solution or the problem was solved. Unfortunately, data collected are 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 (*59*). Therefore, some extrapolation must take place (*60*).

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); whereas output measures just 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 (*61*). Output measures are usually much easier to define and track, however, and are more often under direct agency control (1). Thus, they afford the agency an opportunity for 'proactive management' of the factors involved (*62*). An outcome is usually aggregated from output measures, and may be difficult to measure, as a causal relationship between outputs and outcomes must be determined (*58*). Outcomes may also be impacted by side effects external to measured outputs or other actions of the agency. Outcome measures can also be further designated as intermediate or long-term (i.e., more short-term accomplishments versus desired final result) (*61*). Intermediate outcomes typically contribute to the achievement of related long-term (or 'end') outcomes. Additionally, agencies are likely to have more control over intermediate outcomes than long-term ones, making them easier to strive for. Finally, even if an outcome can be fully determined, it still may not be known why or how the outcome occurred (*63*).

Other types of performance measures include:

- Input measures;
- Process or workload measures;
- Timeliness measures;
- Productivity or efficiency measures (typically a comparison of outputs to inputs);
- Demographic or other workload characteristics;
- Explanatory information; and
- Impacts (1, *61*).

Kaufman also recommends that indicators should relate to ends instead of means, processes, or resources (*64*). 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 indicators 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.

In addition, it is not enough to simply identify the desired measures; rather, the agency will have to continue the process by:

- Locating a source of data;
- Deciding how often data will be collected;
- Determining how data should be manipulated or normalized;
- Setting target values or levels;
- Deciding how often results should be reported and/or used for decision-making;
- Choosing to whom the information should be made available;
- Evaluating the measures for alignment, gaps, and conflicts; and
- Deciding how and when measures should be evaluated and updated (*62*).

Furthermore, a performance measurement matrix is a potentially useful tool for analysis. As an example, a matrix developed for the Delaware Department of Transportation (DelDOT) had outcome measures related to planning goals, and output measures that related to specific policies and actions. The use of time-oriented graphs for presentation is also suggested, which would allow comparison of current performance to past performance, often in a rolling time period format. However, when creating graphs, the Y-axis should be scaled with caution, as different scales can significantly affect perception of results (*62*).

*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 (*65*). 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 (*58*). In addition, the measure should distinguish between means and ends. Literature appears to indicate that ends-oriented performance measures are preferable. Measures should also eliminate confusion concerning which results are the most desirable (*64*). Table 3 lists and describes desirable characteristics of performance measures found in literature (1, *61, 66, 67*).

**Table 3: Characteristics Related to 'Good' Performance Measures**

| Attribute | Description |
|---|---|
| Measurability (Realistic) | • Are required data, analysis methods, tools, and resources available?<br>• Can the necessary level of accuracy be achieved for the measure to be usable?<br>• How reliable are the data sources?<br>• 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 policymakers, agency staff, and other transportation professionals? |
| Usefulness | • Is this measure actually useful to any stakeholders?<br>• 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?<br>• Does the agency have direct or indirect control, and is that control full or partial? |
| Relevance | • "Is the measure relevant to planning/budgeting processes?<br>• Does the reporting of these measures happen often enough to give decision makers the information they need as often as they need it?" (*67*) |
| Consistency | • Is the measure reliable?<br>• 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?<br>• 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?<br>• Is the measure aggregated so much that a 'black box' condition might occur?<br>• "Is there a logical link between this measure and what actions/phenomena affect it?" (*67*) |
| 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?<br>• 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?<br>• Can the measure discriminate between performance during peak and off-peak periods, as well as different daily conditions?<br>• "Does the measure fit well with the time frame of analysis and action?" (*67*) 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?<br>• 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 (*66*).

It is suggested that measures involving costs are minimized, as the costs of doing business are not necessarily indicative of how well a goal was met.  One example given is that spending less on salting the road may indicate a milder winter rather than improved safety or efficiency (*58*).  Additionally, numerical measures that involve quota-like standards can lead to goals being reached without any actual improvements, and should be avoided (*58*).  Additional problems to avoid include:

- Setting easy targets that are sure to be met rather than targets that really match goals or really encourage change;
- Accelerating or delaying activities so that results are reported when desired;
- Sub-optimization of performance of some components to maximize overall system performance;
- Aggregation that hides important details; and
- Segmentation to show good performance and ignore bad segments (*62*).

Other problems may arise, but this set of problems was described as fairly typical.

*Frameworks*

A basic description of the purpose of a framework is to "help organizations to define a set of measures that reflects their objectives and assesses their performance appropriately (*68*)." Many different frameworks have been proposed to help organizations create a well-balanced set of measures.  For example, one of the more popular frameworks is the Balanced Scorecard, first proposed by Kaplan and Norton in 1992.  This framework focuses on four different perspectives of the organization—the financial perspective, the customer perspective, the internal perspective, and innovation and learning (*69*).  The idea behind the Balanced Scorecard is to provide balance "between short- and long-term objectives, between financial and nonfinancial measures, between lagging and leading indicators, and between external and internal performance perspectives (*69*)."  Thus, a multidimensional approach is provided by the framework, as opposed to a common business approach of focusing on historic, short-term, and strictly financial performance.  Another framework is the Performance Prism, proposed by Kennerley and Neely in 2002, which includes a focus on the stakeholder perspective of performance (including, for example, investors, customers, and employees) (*68*).  This framework focuses especially on achieving stakeholder satisfaction—thus, measures relate to strategies required, processes needed to achieve strategies, and the capabilities needed to support the required processes.  Additionally, measurement of needed stakeholder contribution is included.

While many of the proposed frameworks are intended for the business sector, some ideas behind them are certainly applicable to the public sector as well.  Within a public agency, a framework is needed to aid in the selection and evaluation of performance measures, and to help ensure that the measures support achievement of agency goals and objectives.  While no generic performance measurement framework specifically for the public sector has been developed, there have been attempts to create frameworks applicable for public agencies (*70*). One example, the Moullin framework, focuses on the dimensions of "strategy or key performance outcomes, service quality, operational excellence, financial management, and innovation and learning" (*70*). Hence, this model is somewhat an adaptation of the Balanced Scorecard for the public sector. A framework like the Performance Prism could also be utilized to help identify and sort stakeholders. Identifying stakeholders is essential to good communication of results (*71*). On the other hand, too much focus on stakeholders, who often have conflicting views, could result in a framework that is too complex.

Some sort of framework is needed so that performance can be put in context and interpreted, and can thus yield useful information (*71*). Environmental performance measures should be organized into a framework to assure that they actually fulfill a purpose and can be useful to the user (*72*). Additionally, such a framework can be integrated with broader performance assessment approaches rather than focus only on performance measures (*72*).

*Usefulness of Performance Measurement for Emissions and Air Quality*

Although some measurements of rainfall acidity exist from the nineteenth century, measurement of air pollution is a relatively recent activity—chemical analysis of pollutants in the air was not developed until the twentieth century (*73*). Air pollution levels need to be measured in order to establish controls. Minimization of air pollution is desirable in order to minimize adverse effects on the ecosystem, human health, structures, and even visibility. At the same time, however, goals such as mobility, accessibility, and economic development are desirable within the transportation field (*67*). Problems arise when these goals conflict, since in many ways they may oppose each other. In fact, environmental goals may be overlooked by policymakers in the face of other societal concerns like mobility. The use of performance measurement could help ensure that environmental and air quality considerations "are being consistently and transparently considered in public policy" (*72*).

Additionally, the 2005 Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) includes environmental quality as one of eight factors to consider in planning activities. This planning factor includes such objectives as protecting the environment, promoting energy conservation, and improving the quality of life (1). Addressing air quality problems would help in attaining all of these objectives and should be considered as part of any transportation planning, program, or project. Performance measurement can thus aid planners and other agency personal in making sure that the agency is working toward better air quality.

As part of the National Cooperative Highway Research Program (NCHRP) project 25-25, agencies that dealt with transportation were investigated, and five were found to use environmental performance measures—two Metropolitan Planning Organizations (MPOs) and three Departments of Transportation (DOTs). The primary reason given was "the ability to evaluate existing programs and projects, and to communicate the results…within the agency" (1). Other motivations for environmental performance measures included:

- Linking statewide goals and projects or programs;
- Ease in communicating program and project results with the public;
- Legislative mandates;

- Assistance with agency resource allocation;
- Benchmarking;
- Motivation and direction for employees;
- Help with problem solving; and
- Help with identifying efficiencies or inefficiencies (1).

All of the above motivations could be applied to performance measurement in general. However, these advantages illustrate that environmental performance measures do not just keep policymakers from ignoring environmental issues, but also serve a vital purpose within the agency.

Within the transportation sector, different dimensions should be considered when developing performance measures (*67*). For example, different travel modes may be considered, such as road, rail, and air. A performance measure may apply only to transit service, such as ridership, or to many different modes, such as miles traveled. Measures are developed based on different transportation concerns, and often relate to different applications such as planning or operation and maintenance. A timeframe should also be specified—in other words, performance may be evaluated in the long- or short-term, and may be observed at a single point in time, or tracked as a continuous trend. Finally, performance measures can vary in their degree of refinement; for example, the measure may be either a primary or secondary indicator of performance.

*Data Requirements*

The data required are 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 (*74*). Therefore, data that are already available to the agency are most 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. In addition to determining data requirements, a source for that data must be identified. Additionally, the frequency of data collection and reporting should depend, at least in part, on the timing needs of decision-makers.

For successful use, data quality should be a high priority. Suggested criteria of data quality include accuracy (or rate of error), completeness, consistency, and currency (or "age of data relative to time of collection and collection frequency") (*74*). Common problems with data collection include:

- Collecting so much data it cannot be used effectively;
- Not collecting enough data;
- Summarizing data to the point that it becomes meaningless;
- Collecting inconsistent, conflicting, or unnecessary data;
- Focusing only on the short-term;
- Not making use of data for appropriate decisions; and
- Collecting data too often or not often enough (*57*).

In addition, many methods exist for collecting data, although not all may be appropriate for the type of data needed. Methods include:

- Records kept by the project, program, or agency;
- Site inspections or observations;
- Use of technical equipment;
- Surveys and interviews;
- Purchasing statistics;
- Peer reviews or expert panel evaluations;
- Quantitative metrics for research and development;
- Economic methods;
- Cost-benefit or cost effectiveness studies;
- Case studies;
- Content review; and
- Focus groups (*74*).

In addition to applicability, the cost and time commitment must be considered when selecting a data source or method of collection.

**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 project the focus is on 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 and energy 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 pricing will be further explored in this report, as such a system will give a financial incentive to reduce driving, which will in turn improve air quality overall. Thus, in this project pricing is used to achieve air quality goals rather than improving congestion or generating revenue, as is often done. For any pricing scheme, however, many different components would have to be considered, including technology requirements, equity, and public perception.

The next chapter 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, literature review contributes significantly to the process of establishing a user-fee system in later chapters.

## CHAPTER 3:  DEVELOPING A FRAMEWORK OF PERFORMANCE MEASURES

### Approach

The idea behind this project was to address air quality and energy concerns with road pricing. Performance measurement is used achieve set goals by identifying certain areas for improvement and quantifying how various levels of improvement relate to goal attainment.  For this project, 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 and energy consumption levels.

*Project 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 project scope as they are unlikely to fall within the purview of an MBUF system.  Transit-related measures were also 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 4.

**Table 4:  Mobile Categories Used for This Project**

| 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 (RVs) |
| | Buses | Includes intercity buses, transit buses, and school buses |
| | Combination Trucks | Includes short-haul and long-haul combination trucks |

However, much of the analysis discussed in later chapters applies only to light-duty vehicles, as necessary data were not readily available for heavy-duty vehicles.

*Assumptions*

There were many assumptions taken that contributed to the direction taken with goals, objectives, and measures.  One of the primary assumptions within this project is that the entire focus is on air quality and energy goals.  In other words, 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. However, in this case such important factors were not considered as air quality and energy concerns were deemed more critical.

Another very important assumption is that the necessary technology would be available to implement the system that will be developed. 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 include location, time, and second-by-second speed data. In addition, it was assumed that every driver owns 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. On a similar note, a high level of public acceptance of such technology is also assumed for the purpose of this research. There are currently many negative perceptions associated with fee systems that might utilize location data, as provided by GPS, for assessment. Many people do not like the idea of 'being tracked' in their movements, and have significant privacy concerns. However, addressing such concerns is not within the scope of this project.

**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 4 (*75*).

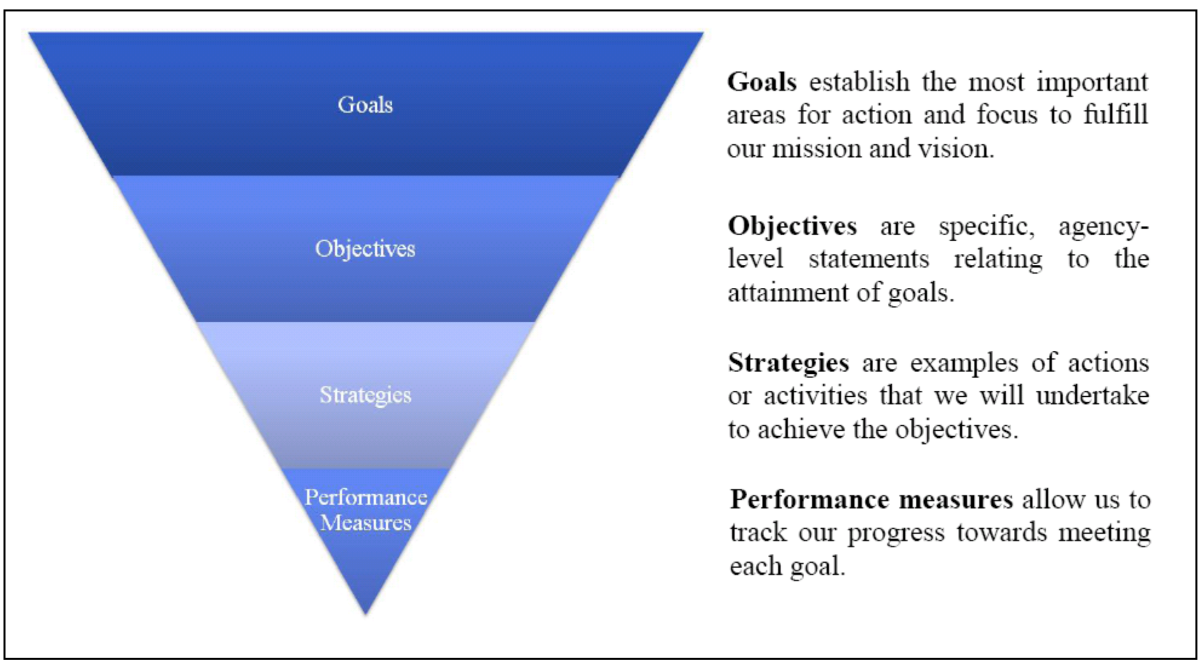


**Figure 4: Illustration of goals, objectives, and performance measures.**

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.

*Identification and Selection of Goals*

The primary purpose of the mileage-based fee system developed in this project 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 should 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 project 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.

*Identification and Selection of Objectives*

Objectives for this project 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 that the emissions and the impacts of vehicle emissions can be reduced and include objectives related to both vehicle performance as well as driver behavior. The selected objectives are shown below in Table 5.

**Table 5: Original Project Objectives and Relation to Goals**

| Objectives: | | 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 - | Encourage shorter trips (trips with lower emissions) or fewer trips | ● | ● | | |
| 2 - | Discourage driving in a specific sub-area; e.g., a specific section or whole non-attainment (NA) area (less emissions in the area) AND/OR during a certain time; e.g., ozone days, or in hours that have high pollutant concentrations | ● | ● | ● | ● |
| 3 - | Encourage driving lower emissions vehicles (influenced by such things as vehicle age, classification, fuel type, presence of retrofitted technologies, etc.) | ● | | ● | |
| 4 - | Encourage driving more fuel efficient vehicles (influenced by such things as vehicle age, classification, fuel type, presence of retrofitted technologies, etc.) | | ● | | ● |
| 5 - | Encourage using public transportation | ● | ● | | |
| 6 - | Discourage operating the vehicle in a certain way; e.g., high speeds, high acceleration, idling, or in congestion | ● | ● | ●* | ●* |
| 7 - | Encourage freight efficiency/discourage empty freight trips | ● | ● | | |
| 8 - | Encourage participation in training or web-based resources for better driving behavior/eco driving | ● | ● | | |
| *when applied to a specific/applicable sub-area | | | | | |

Most of the objectives can be applied to multiple goals, meaning that some 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. On the other hand, Objective 6 would address Goals 3 and 4, mainly in the area where driving behavior is drastically improved. For example, there may be an improvement in human health along a highway corridor if vehicle operations were improved on a large scale. 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 measure level.

While not altered in essence, the final set of eight objectives was reworded to be clearer to a lay person and to better express the idea behind each objective. Therefore, the eight objectives to be addressed through performance measurement and pricing, as well as the applicability of each objective, are shown in Table 6.

**Table 6: Reworded Project Objectives and Descriptions**

| Objectives: | | Application: |
|---|---|---|
| 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 - | Discourage 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 low-income areas, environmentally sensitive areas like wetlands, and ozone action days. |
| 3 - | Encourage driving lower emissions vehicles | 'Cleaner' vehicles that emit fewer pollutants per mile would decrease overall emissions. |
| 4 - | Encourage 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 - | Encourage 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 - | Discourage the types of driving 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 - | Encourage 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 - | Encourage participation in training or web-based resources 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. |

As shown, most of the objectives address factors that affect the amount of pollutant or GHG emissions per trip, or per mile. The MBUF will, therefore, be applied to vehicular measures and system measures that help to achieve these objectives. These objectives in turn guided the process of selecting performance measures, as they are metrics against which the pricing system's success in achieving these eight objectives will ultimately be evaluated.

## 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 project. 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. Documents available on state DOT websites were examined for this purpose. Many measures identified in the review of DOT practice were useful for evaluating agency performance, but were not applicable to the project. Instead, measures related to individual vehicles and drivers were investigated. For each objective, the measures identified through literature review and brainstorming sessions are identified. Next, the process behind selection of a final measure to represent the objective is discussed. Finally, the final measure or set of measures for each objective is identified.

*Individual and System-Level Measures*

Performance measures are significantly defined by the measurement units used. For example, a measure of distance traveled must be fully defined—distance could be given in many units, including miles and kilometers. Performance measures can also depend on scale. In this project, both individual-level and system-level measures are used. Individual measures relate directly to the performance of one driver and his or her vehicle. On the other hand, a system measure would relate to the performance for many drivers or vehicles. Such a measure could be defined as a total value, an average value, or any other desired statistic. In this project, average values are typically used; thus, a system measure would relate the average, or typical, value across the system. For example, an individual measure might give the total number of miles a driver travels in a month. The corresponding system measure could relate the average number of miles driven in a month for all drivers in the defined system, such as city or state.

The purpose of using both individual and system measures in this project is to help determine how an individual performs compared to others. For example, with the above measures, a particular driver may drive fewer miles or more miles than average each month. Exactly how many more or less can also be determined—i.e., how much better or worse than average the individual performs. Since performance will influence pricing, performing better than average could be encouraged by lower pricing, while performing worse than average could be discouraged with higher pricing. For this project, system measures will be differentiated by vehicle class so that individuals can be compared to similar vehicle types only.

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

The initial set of potential indicators 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 HOV lane);
- Number of cold starts;
- Mean or median length of trips by mode (or class of vehicles);
- Average amount of emissions per trip;
- Total annual VMT in the area;

- Total annual VMT per capita in the area;
- Mode/vehicle class share for the area; and
- Trip purpose (i.e., necessary versus elective trips).

The initial lists of potential indicators were further refined and narrowed through several brainstorming sessions conducted by TTI researchers specializing in air quality and pricing. Notes from one of the brainstorming sessions are included in Appendix C for reference. 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.

In addition, a VMT measure would in some way incorporate several of the other measures. For example, if drivers know that they must pay per mile, they will be inclined to reduce their number of trips, shorten the length of their trips, carpool more, and reduce elective trips or utilize trip chaining. Thus, most of the above measures would not provide necessary additional information for this framework. Measuring freight ton-miles rather than just VMT would be desirable, but such information was determined to be too difficult to obtain from the freight industry at the present time. The resulting revised measure list is shown below in Table 7.

**Table 7: Revised Measures for Objective 1**

| Individual | System | Description |
|---|---|---|
| Total VMT in the area per payment period/daily/weekly/monthly/annually | Total VMT in the area per mode/vehicle class for the specified period | This measure is vital to the entire framework in that the user would be charged based on the mileage driven, with the rate determined by other measures. Total VMT could help determine total emission levels, and would also be useful in setting prices, especially if some specific amount of revenue was desired. |
| | Average VMT per capita in the area for the specified time period | |

The table shows both the individual side and the system-wide side of this measure, as both are desired for the final framework. A defined timeframe is necessary to fully define the measure, and can also provide for comparison to past or future performance. For a long-term system-wide analysis of performance, VMT per year is likely the appropriate scale. VMT per month could be a useful measure for the individual driver to help them determine how to improve performance. For the purpose of pricing, VMT per billing period would be most suitable. As a system-wide measure, either total VMT across the system or average VMT per capita could be used. While total VMT is needed to determine emission levels across the system, for the purpose of this framework, average VMT per capita was selected. This will allow the performance of the individual driver to be compared to the typical system-wide value for pricing purposes. The system measure would be divided by vehicle class, i.e., passenger cars, passenger trucks, motorcycles, single-unit trucks, buses, and combination trucks. Having separate system measures for each vehicle class allows individual vehicles to be compared to overall performance of similar vehicle types.

*Objective 2: Discourage Driving in a Specific Sub-Area and/or at a Specific Time*

Originally identified indicators 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;
- Total annual (monthly/weekly/daily) VMT in the target area by mode or class of vehicles;
- Total annual (monthly/weekly/daily) emissions in the target area;
- Total annual (monthly/weekly/daily) VMT per capita in the area;
- 'At-risk' species in the area;
- Annual (monthly/weekly/daily) VMT by Mode/vehicle class for the target area;
- Driving during congested times of day (and potentially only certain locations), such as during peak hours;
- Driving during Ozone Action Days;
- Number of Ozone Action Days per year;
- 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. Many of the above suggested indicators could be potentially used as categories, as shown in the description in Table 8.

**Table 8: Revised Measures for Objective 2**

<table>
<tr><th>Individual</th><th>System</th><th>Description</th></tr>
<tr><td rowspan="4">Total annual (monthly/weekly/ daily) VMT in the target area and/or during the target time</td><td>Total or average VMT in target areas/during target times by mode or vehicle class for the specified time period</td><td rowspan="2">VMT recorded when the vehicle is in the target area or during a target time period would be charged a different rate than normal. Potential target areas and times could include:<br>- congested areas;<br>- major freeway or other facility;<br>- Central Business District;<br>- sensitive habitat, such as wetlands;<br>- presence of at-risk species, etc.;<br>- sensitive areas such as schools or hospitals;<br>- nonattainment areas;<br>- low-income neighborhoods (equity?);<br>- during peak periods/rush hour;<br>- during Ozone Action Days;<br>- during weekdays versus weekends; and<br>- during summer versus winter (temperature), etc.<br>The system measure would be used to determine the state of the system during the target times and/or in the target areas, and thus adjust rates appropriately. Vehicle counts could be especially useful for congestion and rush-hour, and may allow more real-time updates of rates.</td></tr>
<tr><td>Could also include vehicle counts in target areas/during target times to determine variable pricing</td></tr>
<tr><td>Or, could use total daily (weekly/monthly/annual) pollution levels in the target area to set variable rates</td><td>If a system measure of daily emissions were collected, the fee could potentially change to reflect current conditions in target areas/times.</td></tr>
<tr><td>Total number of drivers living in the area</td><td>The London cordon toll included some sort of waiver for drivers that lived in the affected area so they would not be unfairly charged too much, since they cannot avoid the area and cannot reduce their trips to the area as much as other drivers. The system measure would indicate how many drivers are affected, and some sort of waiver should be available to them.</td></tr>
</table>

As before, average VMT per capita was later selected as the system measure. Although it could be potentially used, it was decided not to address variable pricing in this project. Additionally, if some geographic areas were selected to have higher fees associated with vehicle travel in that area, some consideration should be given to residents of the areas, as done in the London cordon toll system. Some sort of waiver or reduced rate may be applied to area residents since they cannot avoid trips within the area.

*Objective 3: Encourage Driving Lower Emissions Vehicles*

The initial set of indicators related to Objective 3 includes:

- Vehicle age;
- Vehicle weight or equivalent single axle load (ESAL);

- Vehicle class;
- Measure for if the vehicle is electric, hybrid, or an alternative fuel vehicle (AFV);
- Some sort of waiver or exclusion based on availability or lack of availability for alternative fuels;
- Vehicle gets reported as part of the Texas Commission on Environmental Quality's (TCEQ's) Smoking Vehicle Program;
- Presence or installation of retrofitted technology;
- Engine efficiency;
- Fuel composition and/or octane level;
- Installation of devices such as filters, etc. in trucks to lower emissions;
- Tons of pollutants emitted by type; and
- Use of catalytic converters (however, there is a tradeoff between reducing CO, VOC, and NOx on one hand, and increasing emissions of nitrous oxide and ammonia with three-way catalytic converters, for example).

As demonstrated through this list, applicable indicators for this objective apply directly to aspects of the vehicle itself. During the first brainstorming session, several potential measures were selected from the initial list, as shown below in Table 9.

**Table 9: Revised Measures for Objective 3**

<table>
<tr><th>Individual</th><th>System</th><th>Description</th></tr>
<tr><td>Vehicle Age</td><td>Average vehicle age per vehicle class</td><td>Older vehicles typically emit more and have lower fuel efficiency; however, differences between vehicle models may be greater than between the same model over time. Either a target value would be needed, or rates could differ based on being better than average or a certain percentile.</td></tr>
<tr><td>Vehicle weight or ESALs</td><td>Average weight for different vehicle classes</td><td>Heavier vehicles tend to emit more and consume more fuel, in addition to causing more roadway damage. Either a target value would be needed, or rates could differ based on being better than average or a certain percentile.</td></tr>
<tr><td>Vehicle class</td><td>Mode/vehicle class share for the area</td><td>Alternatively, vehicle class may be an easier measure to use than individual vehicle weight, and does reflect vehicle weight to an extent. Mode shares would indicate the relative impact of each mode (to an extent).</td></tr>
<tr><td>Vehicle emission rating</td><td>Average emissions rating per vehicle class</td><td>From the EPA, this rating would give a good overall indication of the emissions impact of the vehicle. The average rating would be used to determine how well an individual vehicle performs.</td></tr>
<tr><td rowspan="2">Tons of pollutants emitted by type per payment period/daily/ weekly/monthly/ annually</td><td>Average emissions of each pollutant by vehicle class</td><td rowspan="2">A better measure might be the actual amounts of pollutant emitted, although the actual use of the measure would be more difficult and would require some sort of measurement technology on individual vehicles. Again, the system measure would be used to determine impacts system-wide and determine individual contributions.</td></tr>
<tr><td>Total emissions of each pollutant in area over time period</td></tr>
</table>

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 the 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, although imperfectly since only six vehicle classes are being considered for this project, and weights vary among vehicles in each class. Vehicle weight 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. However, vehicle age and vehicle class are needed for heavy-duty vehicles, as the emissions ratings found only apply to light-duty vehicles. In addition, vehicle age and vehicle class would need to be used to determine the emission rating for light-duty vehicles.

*Objective 4: Encourage Driving More Fuel-Efficient Vehicles*

Some of the initial indicators 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
- Measure for if the vehicle is electric, hybrid, or AFV;
- Some sort of waiver or exclusion based on availability or lack of availability for alternative fuels;
- Vehicle gets reported as part of TCEQ’s Smoking Vehicle Program;
- 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);
- Alternatively, could have separate measures for fuel consumption and fuel type;
- 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. Through the first brainstorming session, the list was narrowed, as shown in Table 10. 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 emissions rates.

**Table 10: Revised Measures for Objective 4**

| Individual | System | Description |
|---|---|---|
| Vehicle Age | Average vehicle age per vehicle class | Older vehicles typically emit more and have lower fuel efficiency; however, differences between vehicle models may be greater than between the same model over time. Either a target value would be needed, or rates could differ based on being better than average or a certain percentile. |
| Vehicle weight or ESALs | Average weight for different vehicle classes | Heavier vehicles tend to emit more and consume more fuel, in addition to causing more roadway damage. Either a target value would be needed, or rates could differ based on being better than average or a certain percentile. |
| Vehicle class | Mode/vehicle class share for the area | Alternatively, vehicle class may be an easier measure to use than individual vehicle weight, and does reflect vehicle weight to an extent. Mode shares would indicate the relative impact of each mode (to an extent). |
| Vehicle fuel-efficiency (as stated by the manufacturer or measured in-vehicle) | Average fuel efficiency per vehicle class | Would give a good baseline or simple indication of fuel consumption of the vehicle. Comparison to the average would indicate relative performance. |
| Fuel usage (gallons/payment period) based on fuel type (i.e., gasoline, diesel, alternative fuel) | Average fuel consumption per vehicle class by fuel type | A better measure would be the actual fuel consumed by the vehicle; the fuel type may also be important from an emissions impact. Again, the system measure would be used to determine impacts system-wide and determine individual contributions. |
| | Total fuel consumption in area over time period by fuel type | |

Again, the most desirable measure would be the actual fuel consumed, but this would also be the most difficult to measure. Although the fuel efficiency given by the vehicle manufacturer is only an average value, we believe it will be sufficient for the purpose of the project. Actual fuel efficiency fluctuates depending on driving behaviors and speeds. However, these factors will be represented in some way through other objectives. Thus, fuel efficiency ratings will be used for light-duty vehicles. Unfortunately, such manufacturer ratings are not available for heavy-duty vehicles, so some estimation based on other vehicle characteristics such as vehicle class and age would be necessary.

Finally, as vehicle age is highly applicable to both emissions and fuel efficiency, vehicle age will be considered. Indeed, vehicle age may be the only current data available for heavy-duty vehicles.

*Objective 5: Encourage Use of Public Transportation*

The initial set of indicators related to Objective 5 includes:

- Some sort of waiver associated with transit use, telecommuting, etc.;
- Rail and/or bus ridership;
- Transit availability;
- Passenger volume on public transportation;
- Passenger-miles on public transportation; and
- Number of times per time period a person uses 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, as discussed in Table 11.

**Table 11: Revised Measures for Objective 5**

| Individual | System | Description |
|---|---|---|
| Some sort of waiver associated with transit use, rideshare, etc., measured in number of trips or number of passenger-miles traveled on public transportation per time period (depending on which is easier to track) | Total transit ridership (volume or total number of trips) per time period<br>OR<br>Total (or average per capita) passenger-miles on public transportation per time period | The purpose of this measure would be to give an extra incentive to use transit or telecommuting; however, there should not be a penalty for not taking transit if transit is not available in the area, or is only minimally available. Either trips or passenger-miles would be tracked and used to determine the pricing benefit. The system measures could help to evaluate the availability or convenience of public transportation in the area. |

As mentioned in the Table 11, this measure would not likely 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. As transit may not be available for all users within the system, users should not be penalized for not using transit. Thus, this measure will serve as an incentive to use 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. Finally, while ridesharing and telecommuting are similar to transit ridership for the purpose of this framework, such behaviors would be very difficult to measure. However, just having a per-mile fee for driving would likely encourage such behaviors.

*Objective 6: Discourage the Types of Driving That Increase Emissions*

Identified indicators 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;
- 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 emissions rate of the vehicle. However, through the brainstorming sessions, the list was narrowed to two measures, as shown in Table 12.

**Table 12: Revised Measures for Objective 6**

| Individual | System | Description |
|---|---|---|
| Percent of time speed exceeds a specified speed (e.g., optimum air quality [AQ] speed) | Average speeds on high-speed facilities in the area | In addition to lower speeds, very high speeds are less fuel efficient. However, this measure should not encourage unsafe behavior such as driving significantly slower than the rest of traffic. Thus, the actual speed limits would have to be accounted for. On the other hand, used in conjunction with lowering speed limits, this measure could encourage a change in behavior more than if just the speed limits were changed (which has not been very effective in past attempts). |
| Frequency or percent occurrence of 'aggressive' driving behaviors (i.e., high acceleration, hard braking) | Average frequency or percent of driving that is 'aggressive' | If data could be obtained through GPS or other technology, this would be useful to discourage such aggressive behavior, as it typically increases emissions and fuel consumption. |

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. In addition, only speeds that exceed a determined 'optimal' speed would be considered, rather than including very low speeds. While very low speeds also influence 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. In addition, the framework should encourage driving during less-congested times of the day through Objective 2. So-called aggressive driving behaviors are also especially useful in that such behaviors can be avoided for the most part by the driver. As an actual measure, only one aspect of aggressive driving may be observed for simplicity.

Measures related to this objective would require a technology component such as a GPS system or an on-board diagnostic system. However, this technology is actually available and possible to use. The research team did discuss aspects of this objective, such as current speed limits and safety impacts of encouraging slower driving. However, for the purpose of this research, only reduction of emissions and energy consumption were considered. Finally, this category of measures would be especially difficult to sell to the public. However, discussion and further research is a primary intent of this framework, rather than immediate implementation.

*Objective 7:  Encourage Freight Efficiency and Use of Preferable Freight Modes*

Potential indicators 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. Also, ton-miles for freight would also be a useful indicator.  However, such were determined during the brainstorming sessions to not be practical.  Researchers indicated that such data are currently not available due to the private nature of freight businesses.  Thus, while measures related to this objective may be applicable in the future, for now they will not be used.

*Objective 8:  Encourage Participation in Training or Web-Based Resources for Better Driving Behavior or Eco-Driving*

The indicators associated with Objective 8 include:

- Some sort of waiver associated with going through online training to promote ‘green’ driving habits;
- Control for lack of access to computer or availability of live classes; 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.  Thus, the measure related to this objective is discussed in Table 13.

**Table 13:  Revised Measures for Objective 8**

| Individual | System | Description |
|---|---|---|
| Some sort of waiver or fee reduction associated with going through online training to promote ‘green’ driving habits | Total attendance or use online | To encourage people to at least learn ‘greener’ driving behaviors, some sort of incentive could be given to attend a class or train online.  The actual use of such training would have to be tracked. Providing only online training may be an equity concern, however.  Drivers should not be penalized for not having access to such training. |

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.

**Concluding Remarks**

Performance measurement is used in this project to link pricing to achievement of air quality goals. The relationship among performance measures, objectives, and goals was discussed in this chapter. 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 project is to improve air quality and energy use. 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 directly addressed in this project, as the pricing methods addressed in this framework would be difficult to link to freight movement at this time. 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. The next chapter addresses details of each measure and methods of quantifying results.

## CHAPTER 4: QUANTIFICATION OF SELECTED MEASURES

### 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 and the energy consumed.

*Individual Measure*

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. However, the vehicle class would be an important input so that the individual measure can be compared to the correct system-level measure. Ideally, a GPS system could be used to track mileage, as such a system would be needed for other measures. However, the data for this measure could actually be obtained through periodic odometer readings, as specific location and time data are not needed.

*System Measure*

The system measure would identify the average VMT by vehicle class, which would allow the individual vehicle to be compared to the average value of all similar vehicles. Therefore, the total number of active vehicles in each vehicle class per billing period is needed, as well as the total VMT across each vehicle class. In other words, the total VMT for each vehicle in each vehicle class would need to be totaled. Therefore, the system measure for each vehicle class would be:

$$Average\ VMT\ for\ Vehicle\ Class\ i = \frac{Total\ VMT\ Across\ Vehicle\ Class\ i}{Number\ of\ Active\ Vehicles\ in\ Class\ i}$$

*Data Requirements and Sources*

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.

### 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 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 different rates could be applied to the mileage obtained in this measure rather than one rate being applied to the first measure. However, both measures would be needed for quality assurance since mileage is of utmost importance in this case.

*Individual Measure*

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 and 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 14.

**Table 14: Example of Individual Mileage by Time and Location Categories**

<table>
<tr><th rowspan="3">Area (Location)</th><th colspan="6">Time</th><th rowspan="3">Area Total (miles)</th></tr>
<tr><th colspan="3">Normal Day</th><th colspan="3">Ozone Action Day</th></tr>
<tr><td>AM Peak (miles)</td><td>PM Peak (miles)</td><td>Off-Peak (miles)</td><td>AM Peak (miles)</td><td>PM Peak (miles)</td><td>Off-Peak (miles)</td></tr>
<tr><td>A</td><td>100</td><td>100</td><td>0</td><td>20</td><td>10</td><td>0</td><td>230</td></tr>
<tr><td>B</td><td>50</td><td>50</td><td>75</td><td>20</td><td>10</td><td>15</td><td>220</td></tr>
<tr><td>C</td><td>50</td><td>50</td><td>25</td><td>10</td><td>5</td><td>10</td><td>150</td></tr>
<tr><td rowspan="2">Time of Day Total</td><td>200</td><td>200</td><td>100</td><td>50</td><td>25</td><td>25</td><td>TOTAL</td></tr>
<tr><td colspan="3">500 miles</td><td colspan="3">100 miles</td><td>600 miles</td></tr>
</table>

The above table shows mileage that occurred in three separate areas and at different times. 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 peak periods or in location A. Example areas could include the central business district or main freeways. As stated, the above table is only an example of what could be done for this measure. Mileage that occurred in each area during different times would be tracked over the billing system. Either these individual mileage values or totals for certain times or locations could be used as a measure, or could be utilized in per-mile pricing.

*System Measure*

The system measure would be similar in this case to the system measure under Objective 1. However, in this case the average VMT per vehicle class would have to be calculated based on total VMT across each class, but divided into categories as shown for the individual measure. Each average VMT would then be determined as:

$$Average\ VMT\ for\ Vehicle\ Class\ i\ per\ Category = \frac{Total\ VMT\ Across\ Vehicle\ Class\ i\ per\ Category}{Number\ of\ Active\ Vehicles\ in\ Class\ i}$$

As an example, Table 15 shows potential total mileage summed for all passenger vehicles in the system for the billing period.

**Table 15: Example of System Total Mileage by Time and Location Categories**

| Area (Location) | Time | | | | | | Area Total (miles) |
|---|---|---|---|---|---|---|---|
| | Normal Day | | | Ozone Action Day | | | |
| | AM Peak (miles) | PM Peak (miles) | Off-Peak (miles) | AM Peak (miles) | PM Peak (miles) | Off-Peak (miles) | |
| A | 3500 | 1000 | 800 | 200 | 100 | 250 | 5850 |
| B | 5600 | 4050 | 1750 | 150 | 300 | 150 | 12000 |
| C | 1250 | 1500 | 1250 | 100 | 50 | 100 | 4250 |
| **Time of Day Total** | 10350 | 6550 | 3800 | 450 | 450 | 500 | **TOTAL** |
| | 20,700 miles | | | 1400 miles | | | **22,100 miles** |

If we assume that there are 50 active passenger vehicles in the system, we would get the average mileages shown in Table 16.

**Table 16: Example of System Average Mileage by Time and Location Categories**

| Area (Location) | Time | | | | | | Area Total (miles) |
|---|---|---|---|---|---|---|---|
| | Normal Day | | | Ozone Action Day | | | |
| | AM Peak (miles) | PM Peak (miles) | Off-Peak (miles) | AM Peak (miles) | PM Peak (miles) | Off-Peak (miles) | |
| A | 70 | 20 | 16 | 4 | 2 | 5 | 117 |
| B | 112 | 81 | 35 | 3 | 6 | 3 | 240 |
| C | 25 | 30 | 25 | 2 | 1 | 2 | 85 |
| **Time of Day Total** | 207 | 131 | 76 | 9 | 9 | 10 | **TOTAL** |
| | 414 miles | | | 28 miles | | | **442 miles** |

If the example individual mileage shown in Table 13 was assumed to be an individual that is part of the above system, his or her mileage could be compared to the system averages shown in Table 15.

*Data Requirements and Sources*

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

**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.

*Individual Measure*

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. While older vehicles may not be found in this guide, their score could be determined based on vehicle class, as shown in Figure 5 (*76*). Descriptions of each acronym are located in Appendix A.

| US EPA Federal Light-Duty Vehicle Emission Standards for Air Pollutants | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Tier 2 Program** | | | | | | | | |
| Standard | Model Year | Vehicles | Emission Limits at Full Useful Life (100,000-120,000 miles) Maximum Allowed Grams per Mile | | | | | Air Pollution Score |
| | | | NOx | NMOG | CO | PM | HCHO | |
| Bin 1 | 2004+ | LDV, LLDT, HLDT, MDPV | 0.00 | 0.000 | 0.0 | 0.0 | 0.0 | 10 |
| Bin 2 | 2004+ | LDV, LLDT, HLDT, MDPV | 0.02 | 0.010 | 2.1 | 0.01 | 0.004 | 9 |
| Bin 3 | 2004+ | LDV, LLDT, HLDT, MDPV | 0.03 | 0.055 | 2.1 | 0.01 | 0.011 | 8 |
| Bin 4 | 2004+ | LDV, LLDT, HLDT, MDPV | 0.04 | 0.070 | 2.1 | 0.01 | 0.011 | 7 |
| Bin 5 | 2004+ | LDV, LLDT, HLDT, MDPV | 0.07 | 0.090 | 4.2 | 0.01 | 0.018 | 6 |
| Bin 6 | 2004+ | LDV, LLDT, HLDT, MDPV | 0.10 | 0.090 | 4.2 | 0.01 | 0.018 | 5 |
| Bin 7 | 2004+ | LDV, LLDT, HLDT, MDPV | 0.15 | 0.090 | 4.2 | 0.02 | 0.018 | 4 |
| Bin 8a | 2004+ | LDV, LLDT, HLDT, MDPV | 0.20 | 0.125 | 4.2 | 0.02 | 0.018 | 3 |
| Bin 8b | 2004-2008 | HLDT, MDPV | 0.20 | 0.156 | 4.2 | 0.02 | 0.018 | 3 |
| Bin 9a | 2004-2006 | LDV, LLDT | 0.30 | 0.090 | 4.2 | 0.06 | 0.018 | 2 |
| Bin 9b | 2004-2006 | LDT2 | 0.30 | 0.130 | 4.2 | 0.06 | 0.018 | 2 |
| Bin 9c | 2004-2008 | HLDT, MDPV | 0.30 | 0.180 | 4.2 | 0.06 | 0.018 | 2 |
| Bin 10a | 2004-2006 | LDV, LLDT | 0.60 | 0.156 | 4.2 | 0.08 | 0.018 | 1 |
| Bin 10b | 2004-2008 | HLDT, MDPV | 0.60 | 0.230 | 6.4 | 0.08 | 0.027 | 1 |
| Bin 10c | 2004-2008 | LDT4, MDPV | 0.60 | 0.280 | 6.4 | 0.08 | 0.027 | 1 |
| Bin 11 | 2004-2008 | MDPV | 0.90 | 0.280 | 7.3 | 0.12 | 0.032 | 0 |
| **Tier 1 Program** | | | | | | | | |
| LDV | 1994-2003 | LDV | 0.6 | 0.31 | 4.2 | 0.10 | -- | 1 |
| LDT1 | 1994-2003 | LDT1 | 0.6 | 0.31 | 4.2 | 0.10 | 0.8 | 1 |
| LDV diesel | 1994-2003 | LDV | 1.25 | 0.31 | 4.2 | 0.10 | -- | 0 |
| LDT1 diesel | 1994-2003 | LDT1 | 1.25 | 0.31 | 4.2 | 0.10 | 0.8 | 0 |
| LDT2 | 1994-2003 | LDT2 | 0.97 | 0.40 | 5.5 | 0.10 | 0.8 | 0 |
| LDT3 | 1994-2003 | LDT3 | 0.98 | 0.46 | 6.4 | 0.10 | 0.8 | 0 |
| LDT4 | 1994-2003 | LDT4 | 1.53 | 0.56 | 7.3 | 0.12 | 0.8 | 0 |

*note: the acronyms used in this figure are defined in Appendix A

**Figure 5: EPA Air Pollution Scores**

Thus, for light-duty vehicles, the score would be a fixed value for the vehicle, and could be fairly easily determined.

For heavy-duty vehicles, the EPA does not provide such scores. Therefore, a ranking system of heavy-duty vehicles based on class and year was determined using MOVES rates to compare how much pollutants are emitted by these vehicles. Different rates were given to various pollutants, and average speeds of 35 mph and 60 mph were used for analysis. The year categories used are pre-2004, 2004-2007, 2007-2010, and 2010+. The following methods were used to combine the data and rank the categories:

- Average Emission Rate Method: The emissions rates for NOx, VOC, CO, and $PM_{2.5}$ were averaged and then ranked;
- Average Rank Method: The vehicle and age categories were ranked separately for each pollutant, and these ranks were then averaged; and
- Sum of Emissions Method: The emissions rates were added to obtain a total gram per mile amount, and the sums were ranked.

The resulting ranks are shown in Figure 6.

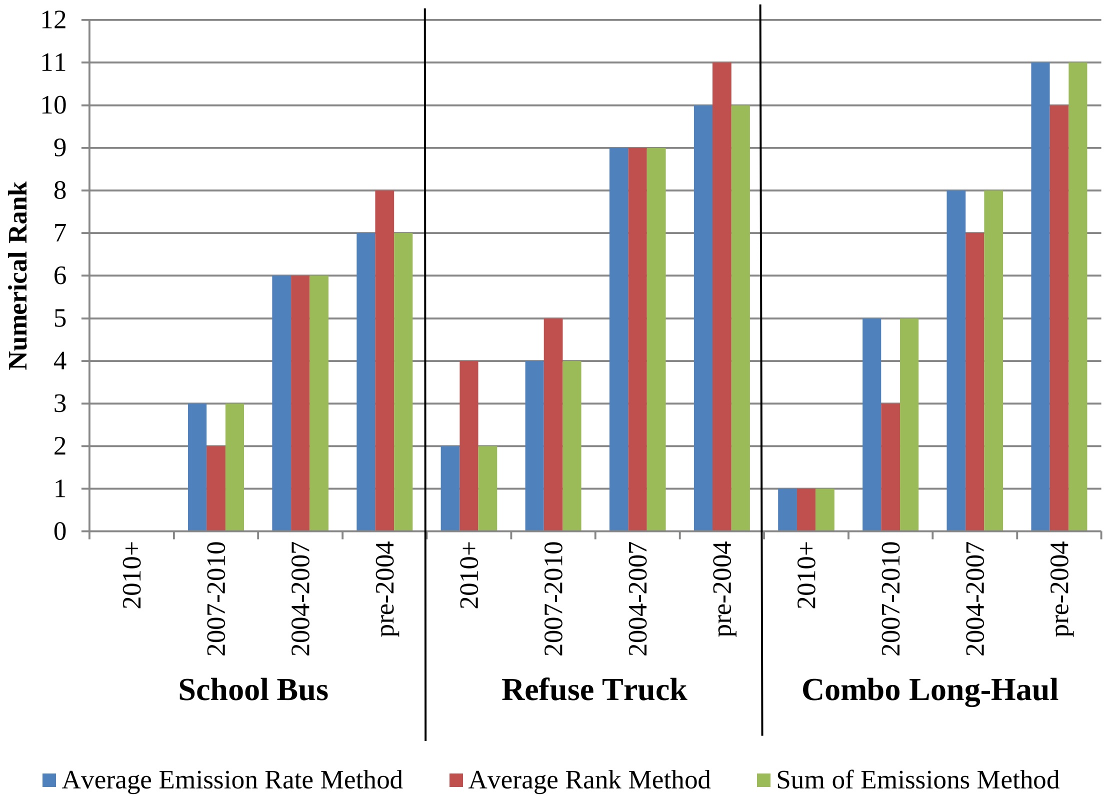


**Figure 6: Ranking of heavy-duty vehicles to determine relative emissions rates.**

Based on the data analyzed, the ranks used for heavy-duty vehicles in this measure are shown in Table 17. However, the ranking is reversed from what is shown above so that the best-performing vehicle is ranked the highest, as it is for light-duty vehicles.

**Table 17: Heavy-Duty Vehicle Emissions Scores**

| Rank | Vehicle Class | Vehicle Age |
|---|---|---|
| 11 | Bus | 2010+ |
| 10 | Combination Truck | 2010+ |
| 9 | Single-Unit Truck | 2010+ |
| 8 | Bus | 2007-2010 |
| 7 | Single-Unit Truck | 2007-2010 |
| 6 | Combination Truck | 2007-2010 |
| 5 | Bus | 2004-2007 |
| 4 | Bus | Pre-2004 |
| 3 | Combination Truck | 2004-2007 |
| 2 | Single-Unit Truck | 2004-2007 |
| 1 | Single-Unit Truck | Pre-2004 |
| 0 | Combination Truck | Pre-2004 |

*System Measure*

The system measure would show the average 'emissions rating' or ranking by vehicle class. This value would be determined as:

$$Average\ "Emissions\ Rating"\ for\ Vehicle\ Class\ i = \frac{\sum(Rating\ Across\ Vehicle\ Class\ i)}{Number\ of\ Active\ Vehicles\ in\ Class\ i}$$

However, since all heavy-duty vehicles are included in the same ranking system, that system measure may be better represented as average rating for all heavy-duty vehicles rather than average rating for single unit trucks, buses, and combination trucks separately.

*Data Requirements and Sources*

Given the vehicle model and year, the EPA Air Pollution Score could be determined with online resources. However, this scoring system only applies to newer vehicles and does not include heavy-duty vehicles at all. Some sort of scoring for other vehicles could be attempted, as above, but such scoring would depend on vehicle age, which is a standalone measure.

**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. However, fuel economy also changes with factors such as speed and acceleration. These factors are considered to be outside the scope of this measure, which will be a fixed value rather than one that changes with time for the sake of simplicity.

*Individual Measure*

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 7 (*77*).

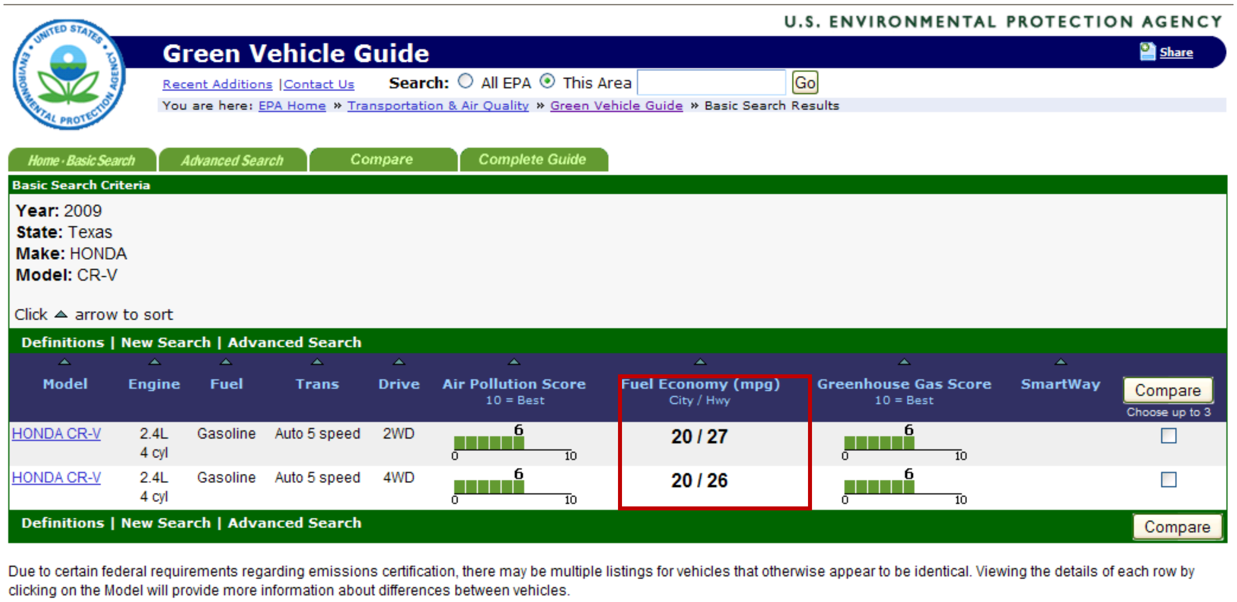


**Figure 7: Green Vehicle Guide fuel economy.**

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. Thus, the individual measure in this case will be an average of the two provided fuel economies for the vehicle, rather than requiring a second-by-second calculation of fuel economy. 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:

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

Of course, 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 Department of Energy (DOE) (*78*).

*System Measure*

Again, the system measure would represent the average across the system by vehicle class. Such a determination would be made as:

$$Average\ Fuel\ Efficiency\ for\ Vehicle\ Class\ i = \frac{\sum(Fuel\ Efficiency\ Across\ Vehicle\ Class\ i)}{Number\ of\ Active\ Vehicles\ in\ Class\ i}$$

*Data Requirements and Sources*

One potential source of data includes the above website, which offers both the Greenhouse Gas Score and vehicle fuel efficiency. However, older vehicles and heavy-duty vehicles would not be as represented online. For older light-duty vehicles, the fuel efficiency may still be known. However, at this time there is little information on heavy-duty vehicle fuel efficiency.

**Measure 5: Vehicle Age**

Vehicle age affects both emissions rates and fuel efficiency. As noted in the previous chapter, the age of the vehicle may currently be the only useful measure for heavy-duty vehicles, as fuel efficiency and emissions ratings are not typically available.

*Individual Measure*

Simply put, this measure would consist of the number of years since the vehicle was manufactured. Alternatively, for heavy-duty vehicles, the manufacturing year of the engine may be most useful. Additionally, ages could be combined into several groups for simplification.

*System Measure*

The system measure would likely be the average vehicle or engine age per vehicle class. Again, the basic formula for such a computation would be:

$$Average\ Age\ for\ Vehicle\ Class\ i\ = \frac{\sum(Age\ Across\ Vehicle\ Class\ i)}{Number\ of\ Active\ Vehicles\ in\ Class\ i}$$

*Data Requirements and Sources*

The vehicle age should be known, as long as the manufacturing year of the vehicle or engine is known.

**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 mileage or mileage-based emissions. 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.

*Individual Measure*

Vehicle classes are not a consideration for this measure, and this measure would not really apply to heavy-duty vehicles, as it would typically involve individual commuters. The measure consists of the number of trips taken on transit.

*System Measure*

Again, the system measure would likely include some sort of average number of trips on transit per person in the system. The measure could also account for the average number of trips only for people who take transit at least once per billing period, so as to better represent the population that does take transit. The percentage of the population that takes transit regularly would also be useful system information.

*Data Requirements and Sources*

To collect such data, some sort of individual identification would likely be needed that could also keep track of the number of trips an individual has taken. A device such as a toll tag could be useful. Transit agencies may already track data such as total trips taken on the transit system for a certain time period, which would be useful for a system measure.

**Measure 7: 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 system rather than driver behavior. In other words, drivers cannot change their behavior to not stop at traffic signals or not slow down in heavy traffic.

*Individual Measure*

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 GPS system 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, 'highway' speed 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:

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

*System Measure*

The system measure would likely report the average percent highway speed above optimal per vehicle class. Thus, an individual's performance could be compared to system-wide performance. This could help control for the effect of higher speed limits in the area.

*Data Requirements and Sources*

A GPS would likely be required to get the second-by-second speed data necessary to calculate this measure. Additionally, time spent on the highway could simply be calculated as all time with speed greater than 50 mph. A GPS system would also allow the possibility of determining highway usage by both time and location. On-board diagnostic data could also potentially be used.

**Measure 8: Time Spent Aggressively Accelerating**

Driving aggressively is considered to increase emissions and fuel consumption. For simplicity, 'aggressive driving' is represented by hard acceleration in this measure. Deceleration was not included here. While some hard or aggressive braking may be due to aggressive driving such as tailgating, some actions may also depend solely on the behavior of other drivers.

*Individual Measure*

This measure is represented as the percentage of time that a threshold acceleration value is exceeded by the vehicle. Similar to the previous measure, some sort of technology such as a GPS system or on-board diagnostic device would be required to track second-by-second acceleration data, and translate that data into a resulting measure. To determine the threshold acceleration values used in this framework, actual GPS data collected by TTI employees was used. The 85$^{th}$ percentile positive acceleration was chosen to represent 'hard' acceleration. In addition, different levels of acceleration are required depending on what speed the vehicle is driving. Therefore, different threshold acceleration values were determined for speeds up to 25 mph, speeds between 25 and 50 mph, and speeds above 50 mph. However, it was decided that speeds between 5 and 25 mph would better represent 'hard' acceleration at low speeds, rather than including acceleration when starting from a stopped position. Thus, the threshold acceleration values obtained are shown in Table 18, as well as the rounded values that will be used.

**Table 18: Threshold (85$^{th}$ Percentile) Acceleration Values**

| Speed | Subject 1 | Subject 2 | Average | Use: |
|---|---|---|---|---|
| 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** |
| *where mph is miles per hour and mph/s is miles per hour per second | | | | |

For the purpose of this project, these values are assumed to apply to all vehicle types. However, it is desirable that the same analysis be performed for heavy-duty vehicles as well, if the GPS data were available; and light-duty vehicles and heavy-duty vehicles tend to be driven differently.

The measure would track the total time where acceleration was greater than these threshold values, depending on the speed the vehicle is traveling, on a second-by-second basis. Thus, the total time representing hard acceleration would be calculated as:

$$\mathit{Total\ Hard\ Acceleration\ Time}\ (sec) = \sum_{i=1}^{3} \mathit{time\ in\ seconds\ acceleration\ is\ above\ threshold\ for\ speed\ range}\ i$$

The final measure would then be calculated as a percentage of the total driving time, as shown below:

$$\mathit{Percent\ Hard\ Acceleration} = \frac{\mathit{Total\ Hard\ Acceleration\ Time}\ (sec)}{\mathit{Total\ Time}\ (\text{sec})} \times 100$$

In addition, the same analysis was undertaken to determine 85th percentile deceleration values, and the results were similar, as shown in Table 19.

**Table 19: Threshold (85th Percentile) Deceleration Values**

| Speed | Subject 1 | Subject 2 | Average | Use: |
|---|---|---|---|---|
| 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** |

If desired, the performance measure could also account for hard braking by including the total hard deceleration time. Later analysis showed that the impact of percent hard deceleration and acceleration was similar to the impact of percent hard acceleration alone.

*System Measure*

Again, the system measure would likely be an average percentage of hard acceleration/ deceleration for each vehicle class. The use of separate vehicle classes would be especially important in this case, as heavy-duty vehicles tend to accelerate and decelerate differently than light-duty vehicles.

*Data Requirements and Sources*

Technology that could track second-by-second speed data would again be needed for this measure. The device could also track acceleration, or acceleration could be calculated later from the second-by-second speed data.

### 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. For example, many drivers may not be aware that excessive highway speeds increase emissions, but that is included in this pricing framework. 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 (*79*). Like the transit measure, this measure would not likely directly impact the mileage-based fee, but could result in some reduction of the final amount owed.

*Individual Measure*

The individual measure would basically consist of whether the individual took the training or not. Such training could be a one-time class, or could even be renewed on a yearly basis.

*System Measure*

The system measure could consist of the average number of system users that participate in training. The total number of users participating could be useful as well.

*Data Requirements and Sources*

If such a training program were implemented, it would likely be online as are many 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.

## Concluding Remarks

The performance measures selected for use in this project were better defined in this chapter. Each of the selected measures has an individual-level component and a system-level component, allowing performance of each individual to be compared to average performance for the vehicle class. Thus, the system-level measures are typically calculated as averages of all individual performance in each vehicle class. 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. 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 chapter discusses the background calculations used for Measures 7 and 8, which relate to highway speed and hard acceleration/deceleration, respectively. The relationship between these driving behaviors and air quality impacts will be better defined.

## CHAPTER 5: IMPACT OF HIGH SPEED AND ACCELERATION

### Overview

Although it was known that emissions increase on the highway with higher speeds and increase with hard acceleration, the actual impact of this driving behavior was not known. Since these factors figure prominently in the pricing framework under development for this research effort, some analysis was undertaken to determine the approximate effect that high speed and hard acceleration have on emissions. GPS data from two vehicles were used to determine the effect of hard acceleration and high speeds. These same data were used in the previous chapter to determine appropriate thresholds for hard acceleration. Between the two vehicles, 13 speed profiles were identified that included some amount of highway driving, in this case taken to be speed above 50 mph. An additional 17 speed profiles that did not include highway driving were identified, and all 30 speed profiles were used to evaluate the effect of hard acceleration. For illustration, graphs of the initial 13 speed profiles are included in Appendix D. These speed profiles were evaluated using the EPA's emissions modeling program MOVES 2010a.

MOVES can be used to obtain emissions rates, as well as total emissions, for many different vehicle types, road types, and pollutants. To obtain emissions rates (i.e., grams per mile of pollutant emitted) MOVES is run at the project level, rather than broader scales such as county or state. Various inputs that can influence emissions 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. Vehicle operating mode distributions are often used; however, speed distributions were available for use in this case. MOVES determines operating mode distribution from these speed profiles for analysis. Emissions are calculated along defined roadways links, and in this project a one-mile link is used. 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 project. 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 was assumed to be a 2011 model, and only basic gasoline was considered (no additives, etc.);
- The road type was considered to be urban restricted access, as highway travel was the primary interest; and
- Pollutants observed include $CO_2$, VOC, NOx, CO, total hydrocarbons (THC), $PM_{2.5}$, and $SO_2$, with only running exhaust emissions used.

The same speed profiles and assumptions were used in MOVES for passenger cars, passenger trucks, and motorcycles, to determine output emissions 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. For actual implementation of this pricing framework, additional analysis would be required using heavy-duty vehicle drive cycles; however, for this project heavy-duty vehicle GPS data were not available. In addition, it is important to remember that only the effects of high speed and hard acceleration are investigated here. In other words, there may be other causes for differences in emission values, but for the purpose of this project, they are assumed to be negligible.

**Highway Speeds above Optimal Air Quality**

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. Table 20 shows a summary of information for each speed profile.

**Table 20: 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% |

Only the speeds greater than 50 mph were used in speed profiles to determine emissions rates. Then, the percent of those highway speeds that were over 60 mph were graphed along with the resulting emission rate to see how the percent of highway speed over 60 mph affected the emissions rate. Figure 8 shows the resulting emissions rate, in grams per mile, for each pollutant type.

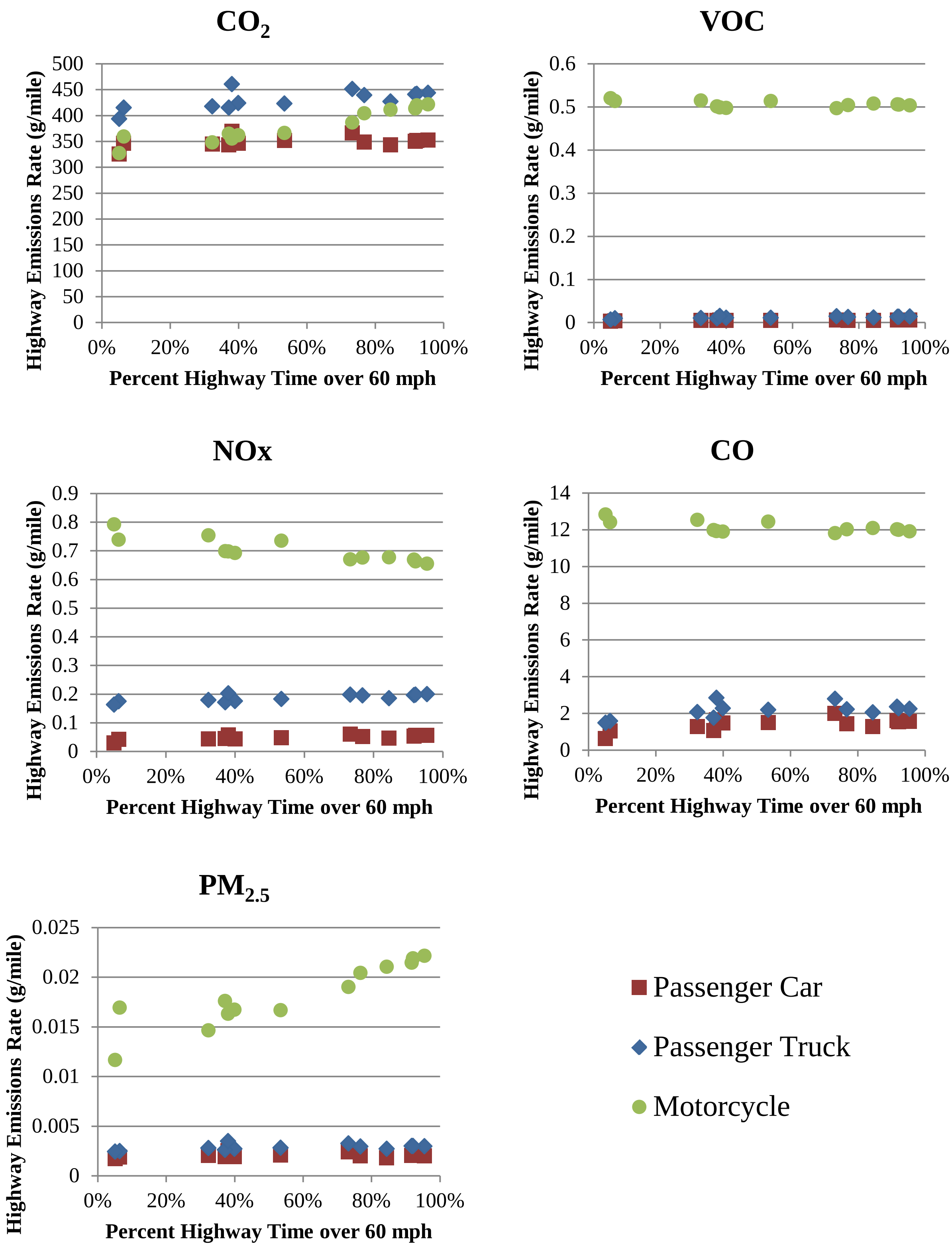


**Figure 8: Emissions rates based on highway speeds over 60 mph.**

For all pollutants except $CO_2$, the emissions rates for motorcycles are much higher than for passenger cars and trucks.  Figure 9 shows emissions rates for passenger cars and trucks only, so that the results may be seen more clearly.

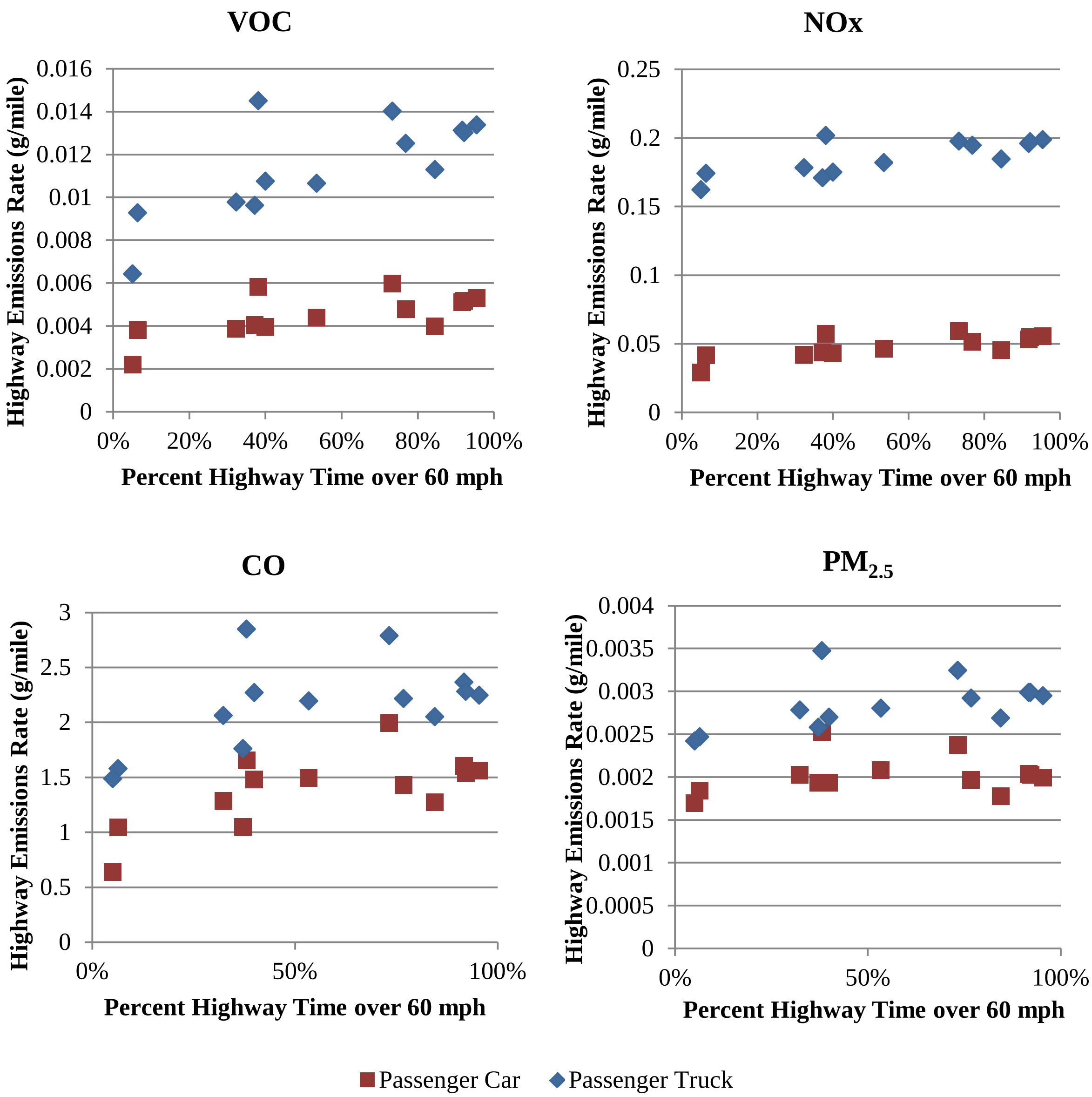


**Figure 9:  Emissions rates based on highway speeds over 60 mph for passenger cars and trucks only.**

As shown, in general the overall emissions rate increases 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 NOx emissions from motorcycles, where the emissions actually decrease with an increased percentage of highway speeds over 60 mph.  CO emissions for motorcycles also appear to decrease, but not to the extent that NOx emissions decrease. 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 project, the above results are assumed to be applicable for motorcycles.

### Hard Acceleration

Additional speed profiles were used to investigate the effects of hard acceleration on emissions. When considering highway speeds, only the profiles that included speeds above 60 mph were used for the evaluation. However, all identified profiles could be used to investigate acceleration. Table 21 summarizes information associated with each speed profile used.

**Table 21: 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% |

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. For the purpose of this project, then, the performance measure will account for both hard acceleration and hard deceleration. Figures 10 and 11 show the resulting emissions rate, in grams per mile, for each pollutant type. The emissions rate is plotted against the independent variable of percent hard acceleration and deceleration.

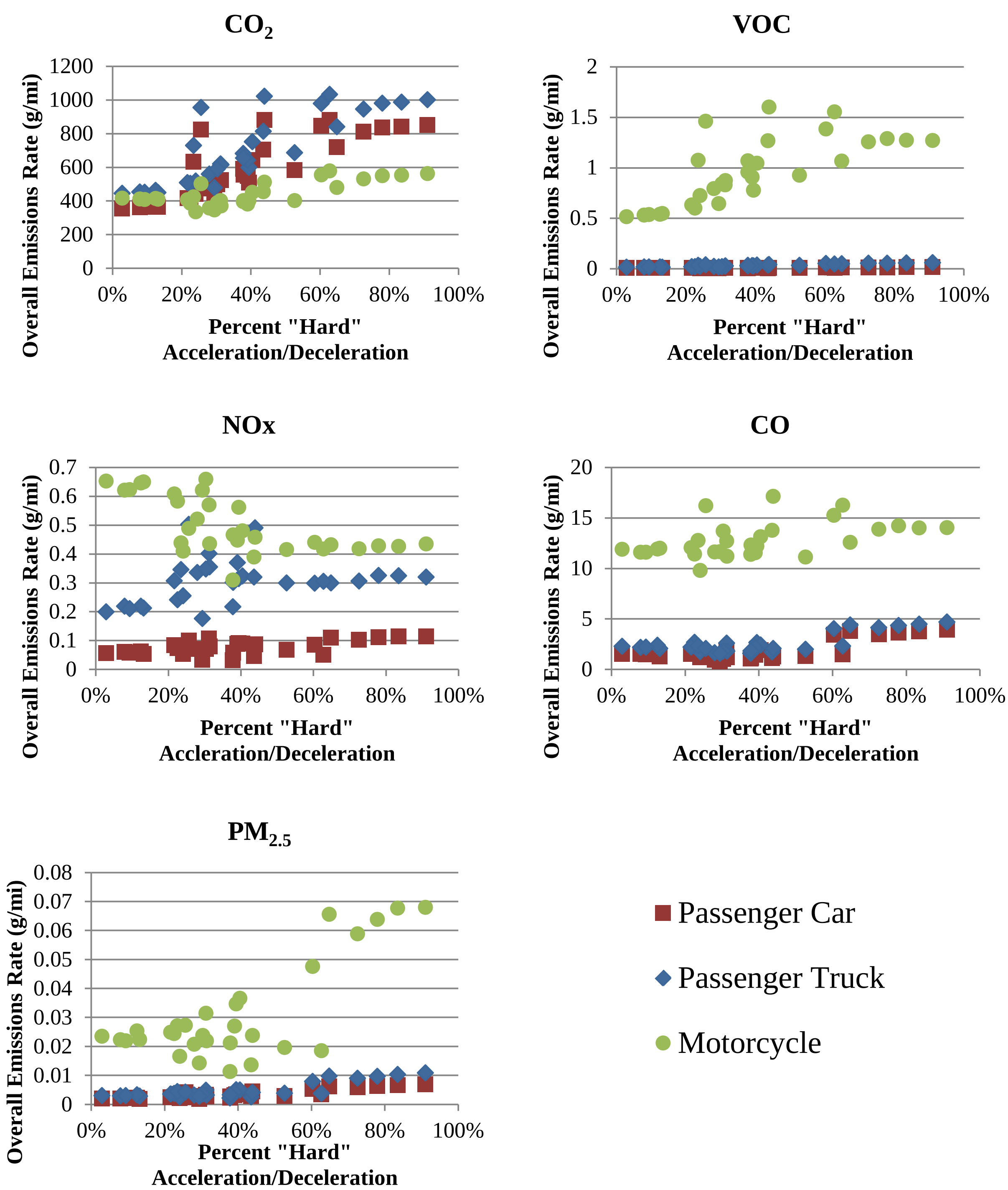


**Figure 10: Emissions rates based on hard acceleration/deceleration.**

Again, not all of the data can be clearly seen due to the higher scale of emissions by motorcycles, although the graph for $CO_2$ does not have this problem. Figure 11 shows results more clearly for passenger cars and trucks.

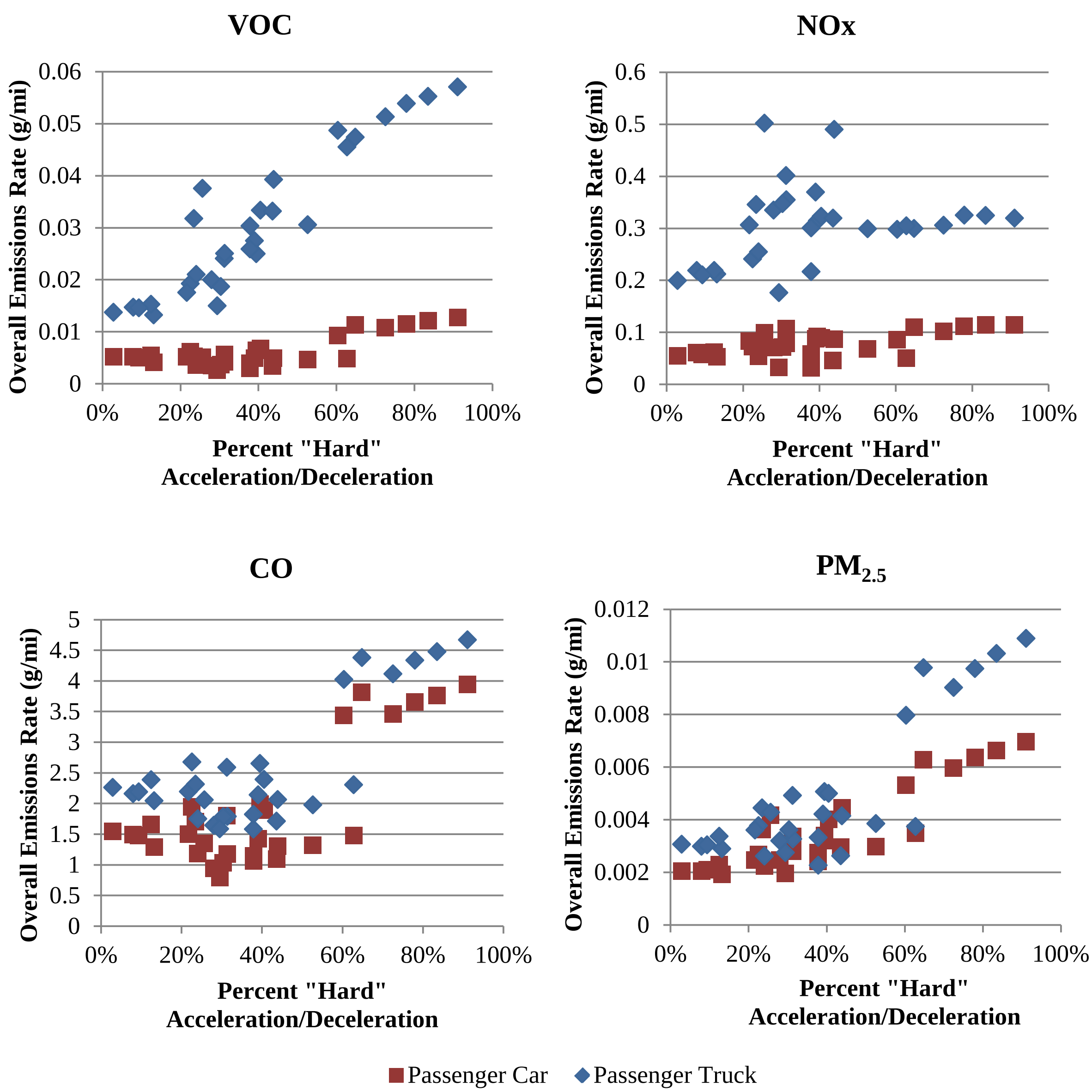


**Figure 11: Emissions rates based on hard acceleration/deceleration for passenger cars and trucks only.**

Figure 11 shows how, in general, the overall emissions rate 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 again 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 project, this result is assumed to be applicable for motorcycles.

## Concluding Remarks

The above analysis was necessary in order to better determine the impacts of driving behavior on emissions, allowing performance on the related measures to be better applied to a pricing framework later. The results show approximately how much various levels of poor driving behavior increase emission rates. As expected, emission rates do increase as highway speed over 60 mph increases and as hard acceleration/deceleration increases, except for the noticeable decrease of NOx emissions for motorcycles. In the next chapter, these results contribute to the calculation of a final performance score for an individual.

# CHAPTER 6:  COMBINING PERFORMANCE MEASURES

## Overview

The performance measures developed for this project 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 are best not applied in determining the mileage fee.  The performance on these measures does not directly affect emissions rates.  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 project affect vehicular emissions 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.

## 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 emissions rates.  An individual's performance on each measure could then be used to scale a base emissions rate up or down. The final emissions rates could then be compared to the system average emissions rates to determine how high the mileage fee should be.

### *Vehicle Emissions Rating*

The purpose of this measure 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 emissions rates. However, it is assumed that poor performance on this measure (i.e., a high emitting vehicle) will not scale up the vehicle's emissions rates.  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.  Also, this measure only applies to light-duty vehicles, as such ratings are not currently available for heavy-duty vehicles.

For this project, the Federal Tier 2 standards will be used, rather than the more stringent Low Emission Vehicle (LEV) II standards used in California.  These 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 project, the standards for NOx, CO, and PM are used, with the assumption that the PM standards apply to $PM_{2.5}$. Additionally, there are two different standards for an air pollution score of one, dependent on vehicle weight.  Table 22 shows the standards used in this project.

**Table 22: 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 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. In other words, a scaling factor would be used to decrease that vehicle's base emissions rates to the above standards if the vehicle has the appropriate air pollution score. This application will be further illustrated in the next section.

*Vehicle Fuel Economy*

For this measure, either average fuel economy or the EPA greenhouse gas score could be used. The fuel efficiencies for different vehicle model years and fuel types, including 85 percent ethanol fuel (E85) and compressed natural gas (CNG), associated with the EPA GHG score are shown below in Table 23 (*80*).

**Table 23: Minimum Fuel Efficiencies (MPG) for EPA Greenhouse Gas Scores**

| GHG Score | Minimum Label MPG (Gasoline) | | | Minimum Label MPG (Diesel) | | | Minimum Label MPG (E85) | | | Minimum Label MPG (CNG) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011-2012 | 2009-2010 | 2008 and Earlier | 2011-2012 | 2009-2010 | 2008 and Earlier | 2011-2012 | 2009-2010 | 2008 and Earlier | 2011-2012 | 2009-2010 | 2008 and Earlier |
| 10 | 48 | 38 | 37 | 55 | 43 | 43 | 35 | 27 | 23 | 39 | 31 | 31 |
| 9 | 39 | 32 | 31 | 44 | 36 | 36 | 28 | 23 | 19 | 32 | 26 | 26 |
| 8 | 33 | 28 | 26 | 37 | 31 | 30 | 23 | 20 | 16 | 26 | 22 | 22 |
| 7 | 28 | 24 | 23 | 32 | 28 | 26 | 20 | 17 | 14 | 23 | 20 | 19 |
| 6 | 25 | 22 | 20 | 28 | 25 | 23 | 18 | 16 | 12 | 20 | 17 | 17 |
| 5 | 22 | 20 | 18 | 25 | 22 | 21 | 16 | 14 | 11 | 18 | 16 | 15 |
| 4 | 20 | 18 | 16 | 22 | 20 | 19 | 14 | 13 | 10 | 16 | 14 | 14 |
| 3 | 18 | 16 | 15 | 20 | 19 | 17 | 13 | 12 | 9 | 14 | 13 | 13 |
| 2 | 17 | 15 | 14 | 19 | 17 | 16 | 12 | 11 | 8 | 13 | 12 | 12 |
| 1 | 1 | 14 | 13 | 1 | 16 | 15 | 1 | 10 | 7 | 1 | 11 | 11 |
| 0 | - | 1 | 1 | - | 1 | 1 | - | 1 | 1 | - | 1 | 1 |

*note: for 2011 and newer vehicles, the '0' score does not apply

The fuel efficiency values for different fuel types were determined by the EPA to meet the same $CO_2$-equivalent ($CO_2$e) standards for each GHG score. Table 24 shows the allowed $CO_2$e rate for the possible GHG scores (*80*).

**Table 24: Carbon Dioxide Equivalent Standards for EPA Greenhouse Gas Scores**

| Vehicle Year | 2011-2012 | | 2009-2010 | | 2008 and Earlier | |
|---|---|---|---|---|---|---|
| GHG Score | Min Grams $CO_2$e per mile | Max Grams $CO_2$e per mile | Min Grams $CO_2$e per mile | Max Grams $CO_2$e per mile | Min Grams $CO_2$e per mile | Max Grams $CO_2$e per mile |
| 10 | 0 | 187 | 0 | 237 | 0 | 302 |
| 9 | 188 | 233 | 238 | 283 | 302 | 360 |
| 8 | 234 | 279 | 284 | 329 | 361 | 428 |
| 7 | 280 | 325 | 330 | 375 | 429 | 493 |
| 6 | 326 | 371 | 376 | 421 | 494 | 560 |
| 5 | 372 | 417 | 422 | 467 | 561 | 616 |
| 4 | 418 | 463 | 468 | 513 | 617 | 693 |
| 3 | 464 | 509 | 514 | 559 | 694 | 752 |
| 2 | 510 | 555 | 560 | 605 | 753 | 837 |
| 1 | 556 | 1000 | 606 | 651 | 838 | 852 |
| 0 | | | 652 | 1000 | 853 | 1000 |

*note: for 2011 and newer vehicles, the '0' score does not apply

The above $CO_2$ rates are used to decrease the vehicle's emissions, if applicable, as with the air pollution score. Scaling factors would be used to decrease a vehicle's base emissions rates to the above standards if the vehicle has the appropriate air pollution score. For this project, if the vehicle's average fuel efficiency is given, it will be converted to GHG score for simplification. However, if desired, the fuel efficiency could be converted directly to $CO_2e$. Additionally, the maximum emission rates above are used rather than the minimums. This will also be further illustrated in the next section.

*Time Traveled at Speed Greater Than Optimal Air Quality Speed*

To see how much effect differing levels of performance have on emissions, the results presented in the previous chapter were used. The resulting emissions were normalized to determine how much emissions would be increased based on performance. Figure 12 shows the resulting normalized results along with trend lines fit to the data.

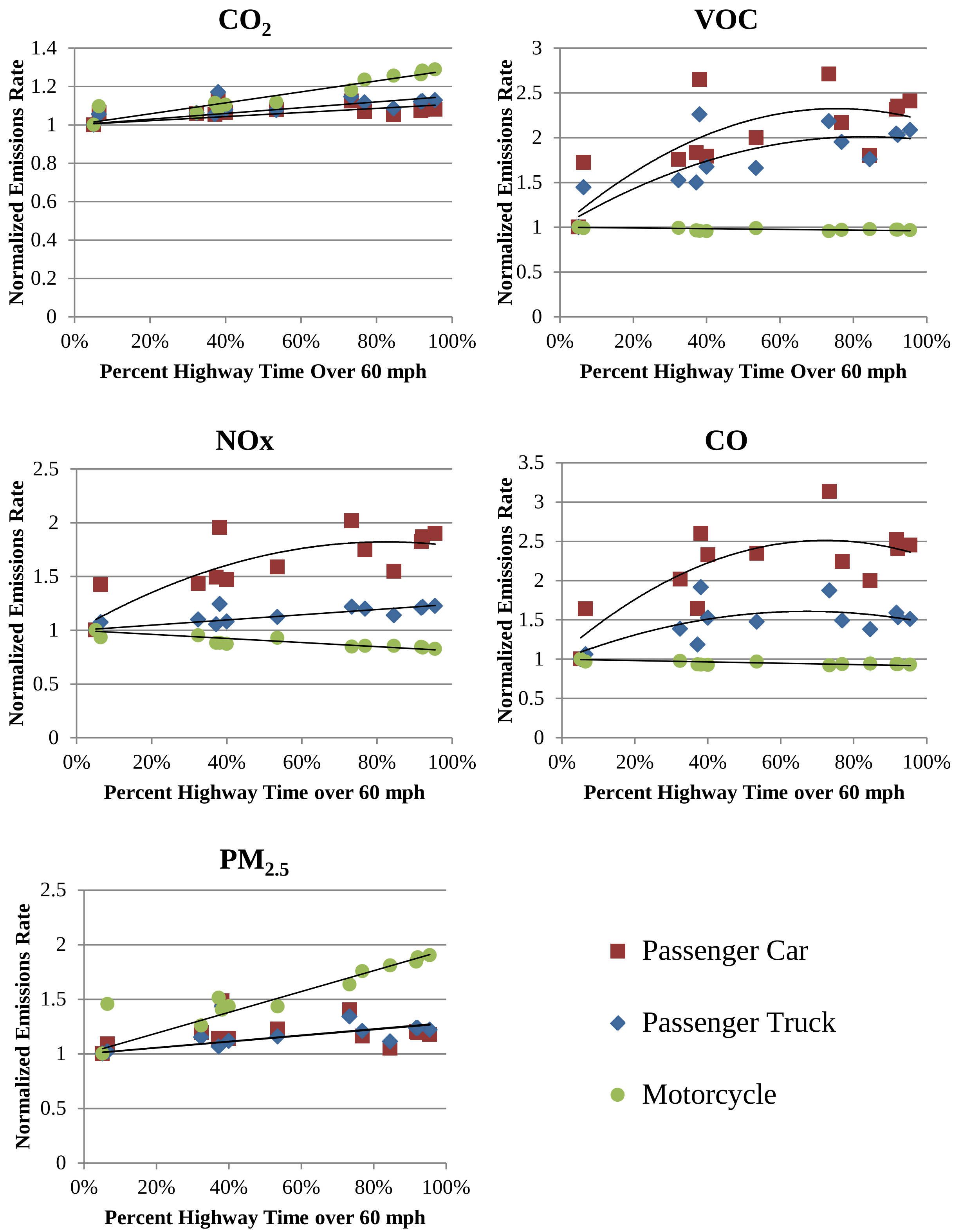


**Figure 12: Normalized emissions rates based on highway speeds over 60 mph.**

Many of the trend lines used were second-order polynomials, which tended to fit the data fairly well. In some cases, a linear trend line was used for simplification. The linear trend line was used when the x-squared factor was negligible and the coefficient of determination ($R^2$ value) was not significantly affected by using a linear trend line. A y-intercept of one was assumed for simplification as well. Table 25 shows the equations used for each trend line, along with the $R^2$ values.

**Table 25: Trend Line Equations Used for Normalized Emissions Rates Based on Highway Speeds over 60 mph**

| Pollutant | Vehicle Class | Equation | R-Squared Value |
|---|---|---|---|
| $CO_2$ | Passenger Car | $y = 0.1076x + 1$ | $R^2 = -0.415$ |
| | Passenger Truck | $y = 0.15x + 1$ | $R^2 = 0.2404$ |
| | 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 | $y = -0.041x + 1$ | $R^2 = -0.106$ |
| 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 | $y = -2.7569x^2 + 3.9809x + 1.0743$ | $R^2 = 0.6077$ |
| | 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 | $y = 0.2779x + 1$ | $R^2 = -0.259$ |
| | Passenger Truck | $y = 0.2859x + 1$ | $R^2 = 0.1639$ |
| | Motorcycle | $y = 0.9526x + 1$ | $R^2 = 0.773$ |

The above trend line equations are used to determine the scaling factors for this performance measure. One assumption is that a performance of driving 0 percent above 60 mph on the freeway would not increase the baseline emissions rates for the individual—thus, the y-intercepts were all set to equal one. The above trend lines are also assumed to be an accurate representation for the three light-duty vehicle categories. Finally, for concave trend lines, the scaling factor is assumed to reach a maximum value and remain at that value even when performance worsens, since we are assuming that increasing the percent of highway driving above 60 mph will only increase emissions. Similarly, any scaling factor less than one is assumed to be one. Table 26 shows possible scaling factors for a passenger car, as an example.

**Table 26: Example Scaling Factors for Highway Speeds over 60 mph**

| Percent Hard Acceleration/ Deceleration | Pollutant | | | | |
|---|---|---|---|---|---|
| | $CO_2$ | VOC | NOx | CO | $PM_{2.5}$ |
| 0 | 1 | 1 | 1 | 1 | 1 |
| 0.2 | 1.022 | 1.608 | 1.351 | 1.686 | 1.056 |
| 0.4 | 1.043 | 2.031 | 1.604 | 2.151 | 1.111 |
| 0.6 | 1.065 | 2.268 | 1.761 | 2.396 | 1.167 |
| 0.8 | 1.086 | 2.324 | 1.821 | 2.437 | 1.222 |
| 1 | 1.108 | 2.324 | 1.822 | 2.437 | 1.278 |

In order to determine the scaling factors for heavy-duty vehicles, a similar analysis would have to be conducted using heavy-duty vehicle drive cycles, which were not available for this project. Therefore, for the purpose of this project, we will assume scaling factors of one for all heavy-duty vehicles.

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

$$New\ Emissions\ Rate = Base\ Rate \times \left(\%Nonhighway + (\%Highway) \times (Scaling\ Factor)\right)$$

For example, if half of the travel occurred on highway facilities and the scaling factor were 2, then the new emissions rate would be 1.5 times greater rather than twice as large.

*Time Spent Aggressively Accelerating*

In a similar way to the high highway speed measure, emissions from the previous chapter were normalized and graphed based on high acceleration/deceleration. The resulting emissions were normalized to the lowest value to see how much emissions would be increased based on performance. In other words, the normalized rate shows how many times greater each emissions rate is than the lowest emissions rate; thus, there is no unit of measure. Figure 13 shows the resulting normalized results along with trend lines.

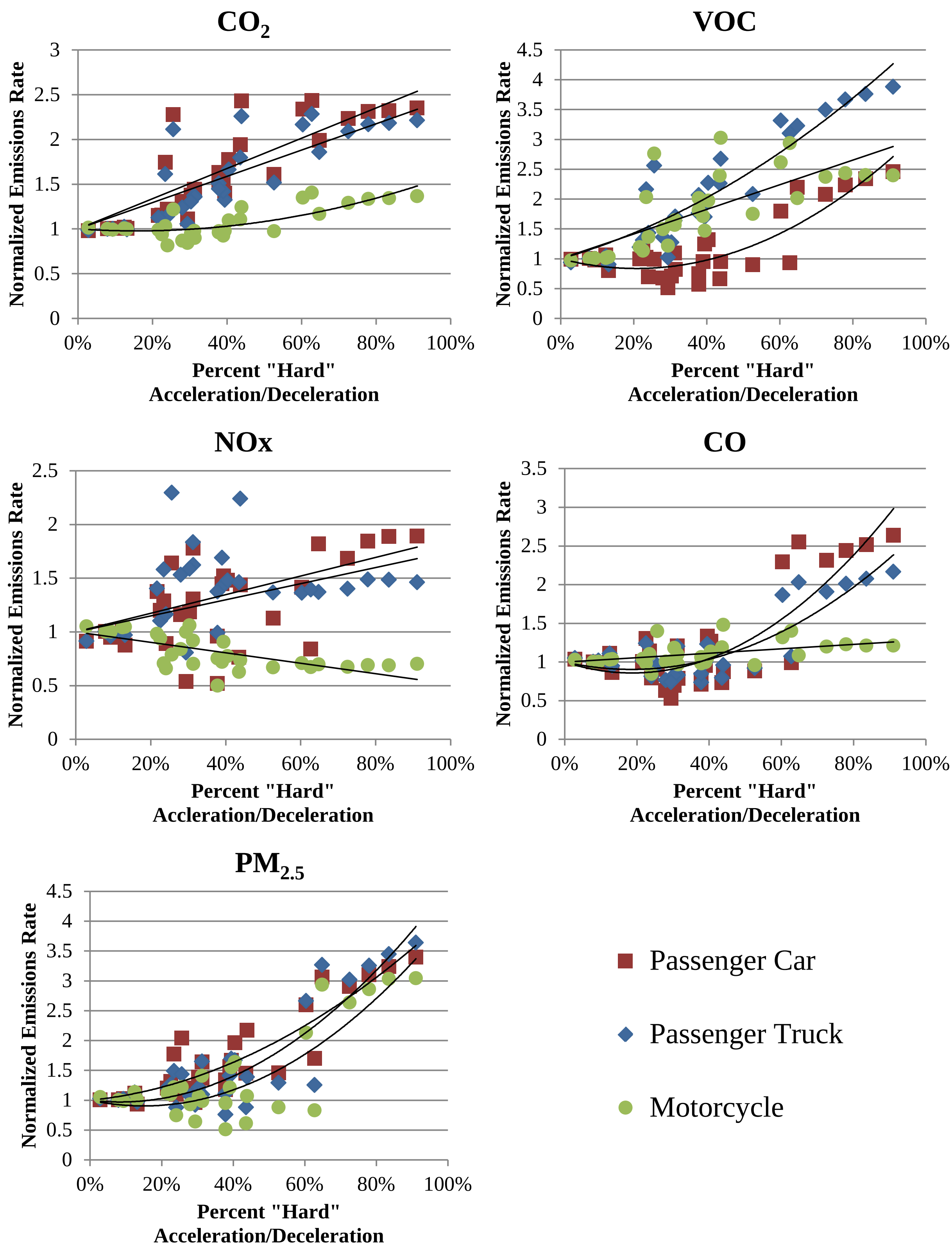


**Figure 13: Normalized emissions rates based on hard acceleration/deceleration.**

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 significantly affected by using a linear trend line. Table 27 shows the equations used for each trend line, along with the $R^2$ values.

**Table 27: Trend Line Equations Used for Normalized Emissions 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 | $y = 0.8828x^2 - 0.2765x + 1$ | $R^2 = 0.616$ |
| 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 | $y = 0.8654x + 1$ | $R^2 = -0.015$ |
| | Motorcycle | $y = -0.4855x + 1$ | $R^2 = 0.429$ |
| 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 | $y = 0.2831x + 1$ | $R^2 = 0.235$ |
| $PM_{2.5}$ | 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 | $y = 4.2559x^2 - 1.2711x + 1$ | $R^2 = 0.7194$ |

The scaling factors used for this performance measure are determined by the above trend line equations. The same assumptions used for the previous performance measure apply, namely:

- Zero percent hard acceleration/deceleration would result in a scaling factor of one, and thus would not increase the baseline emissions rates for the individual;
- The above trend lines are assumed to be an accurate representation for the three light-duty vehicle categories;
- For concave trend lines, the scaling factor is assumed to reach a maximum value and remain at that value even when performance worsens, since it is assumed that increasing the percent of hard acceleration/deceleration will only increase emissions; and
- Any scaling factor less than one is assumed to be one.

As an example, Table 28 shows scaling factors for several different percentages of hard acceleration/deceleration for a passenger car.

**Table 28: 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 |
| 0.2 | 1.338 | 1 | 1.150 | 1 | 1.219 |
| 0.4 | 1.675 | 1 | 1.299 | 1.043 | 1.635 |
| 0.6 | 2.013 | 1.421 | 1.449 | 1.551 | 2.249 |
| 0.8 | 2.350 | 2.168 | 1.598 | 2.383 | 3.060 |
| 1 | 2.688 | 3.218 | 1.748 | 3.541 | 4.069 |

Again, the same analysis could be done to determine scaling factors for heavy-duty vehicles, but drive cycles specific to heavy-duty vehicles would be required.

## Applying Performance Measures

The above performance measures affect emissions rates of vehicles, specifically light-duty vehicles for this project. The results from an individual's performance would be used to increase and decrease the base emissions rate expected for that vehicle. The resulting emissions rate could then be compared to other vehicles within the same vehicle class and other vehicles in general to determine how that vehicle performs compared to system averages. Such a comparison would make use of system-wide performance measures. System-wide performance would likely be computed with data from the previous billing period. However, such a matter is outside the scope of this project.

In order to apply performance in this way, baseline emissions rates must be established for each individual vehicle. For this project, we assumed that the vehicle's baseline emissions rates would be determined based on vehicle class and vehicle age. In addition, 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 rates for these model years and for each vehicle class were calculated using the EPA's MOVES program.

*MOVES Baseline Emissions Rates*

Unlike previous MOVES analysis, national averages provided by the program were used when available, including national-level operating mode distributions. The following assumptions were used:

- 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 88.5 degrees Fahrenheit, with a relative humidity of 55.6 percent;
- Light-duty vehicles were assumed to be gasoline vehicles and heavy-duty vehicles were assumed to be diesel vehicles;
- 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 and 60 mph 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 across the above model year groups for each vehicle class. Additionally, researchers assumed the emissions rates at 60 mph to be applicable for restricted access facilities and the emissions rates at 35 mph to be applicable for unrestricted access facilities. These two rates were averaged to determine the final base rates that would be used for each vehicle class. Tables 29 through 34 show the calculated base rates for each vehicle class.

**Table 29: MOVES Base Emissions 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 |
| 2004-2008 | 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 30: MOVES Base Emissions 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 |
| 2004-2008 | 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 31: MOVES Base Emissions 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 |
| 2004-2008 | 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 |

**Table 32: MOVES Base Emissions Rates for Single-Unit Trucks**

| Model Year | Averaged Pollutant Rate in g/mile on Urban Facilities | | | | |
|---|---|---|---|---|---|
| | $CO_2$ | VOC | NOx | CO | $PM_{2.5}$ |
| 2010+ | 2284.648 | 0.053 | 1.169 | 0.433 | 0.030 |
| 2007-2009 | 2283.730 | 0.068 | 4.895 | 0.551 | 0.037 |
| 2004-2008 | 2281.888 | 1.164 | 9.791 | 3.934 | 0.864 |
| 2000-2003 | 2279.143 | 1.189 | 15.108 | 7.277 | 0.933 |
| 1996-1999 | 2270.489 | 1.198 | 21.861 | 8.391 | 1.117 |
| 1992-1995 | 2243.114 | 1.197 | 24.481 | 8.391 | 1.266 |
| 1988-1991 | 2208.565 | 1.197 | 29.736 | 8.391 | 1.237 |
| pre-1988 | 2146.595 | 1.197 | 34.109 | 8.391 | 3.102 |

**Table 33: MOVES Base Emissions Rates for Buses**

| Model Year | Averaged Pollutant Rate in g/mile on Urban Facilities | | | | |
|---|---|---|---|---|---|
| | $CO_2$ | VOC | NOx | CO | $PM_{2.5}$ |
| 2010+ | 1539.685 | 0.053 | 0.773 | 0.391 | 0.014 |
| 2007-2009 | 1538.965 | 0.070 | 3.517 | 0.514 | 0.017 |
| 2004-2008 | 1537.503 | 1.306 | 7.033 | 4.021 | 0.466 |
| 2000-2003 | 1535.320 | 1.600 | 8.119 | 4.806 | 0.506 |
| 1996-1999 | 1528.446 | 1.798 | 13.746 | 5.329 | 0.856 |
| 1992-1995 | 1506.720 | 2.102 | 16.101 | 6.195 | 0.978 |
| 1988-1991 | 1479.293 | 1.644 | 19.541 | 5.143 | 0.970 |
| pre-1988 | 1430.098 | 1.595 | 22.407 | 5.275 | 1.528 |

**Table 34: MOVES Base Emissions Rates for Combination Trucks**

| Model Year | Averaged Pollutant Rate in g/mile on Urban Facilities | | | | |
|---|---|---|---|---|---|
| | $CO_2$ | VOC | NOx | CO | $PM_{2.5}$ |
| 2010+ | 2648.038 | 0.054 | 1.282 | 0.443 | 0.031 |
| 2007-2009 | 2647.027 | 0.070 | 5.500 | 0.570 | 0.038 |
| 2004-2008 | 2645.022 | 1.227 | 11.000 | 4.190 | 0.916 |
| 2000-2003 | 2642.010 | 1.335 | 16.801 | 7.650 | 1.012 |
| 1996-1999 | 2632.526 | 1.412 | 25.087 | 8.859 | 1.395 |
| 1992-1995 | 2602.561 | 1.521 | 28.459 | 9.060 | 1.615 |
| 1988-1991 | 2564.739 | 1.405 | 34.560 | 8.626 | 1.551 |
| pre-1988 | 2496.897 | 1.474 | 39.639 | 8.327 | 3.043 |

For reference, the emissions rates for both speeds on both facility types are provided in Appendix E. These base emissions rates are then selected based on vehicle class and model year. These are the rates that are then scaled up or down based on the four mentioned performance measures. The percentages of highway speeds over 60 mph and hard acceleration/deceleration are used as described in the previous section. The derived scaling factors are multiplied by their corresponding base rates to scale up the vehicle's emissions. The scaling factors for air quality score and fuel efficiency are described below.

*Applying Emissions Rating and Fuel Efficiency*

The scaling factors associated with these measures are intended to decrease the base emissions rates to the maximum allowed grams per mile, if the standard is lower than the given base rates. Thus, the scaling factors are calculated as:

$$Scaling\ Factor = \frac{Federal\ Tier\ 2\ Standard\ Maximum\ Allowed\ g/mi}{Base\ Emission\ Rate\ g/mi}$$

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. Of course, this measure is also only applicable to passenger cars and trucks currently. Since consideration is only given to decreases to base emissions rates for this project, most air pollution scores were disregarded. Figure 14 further illustrates the process used to determine these scaling factors.

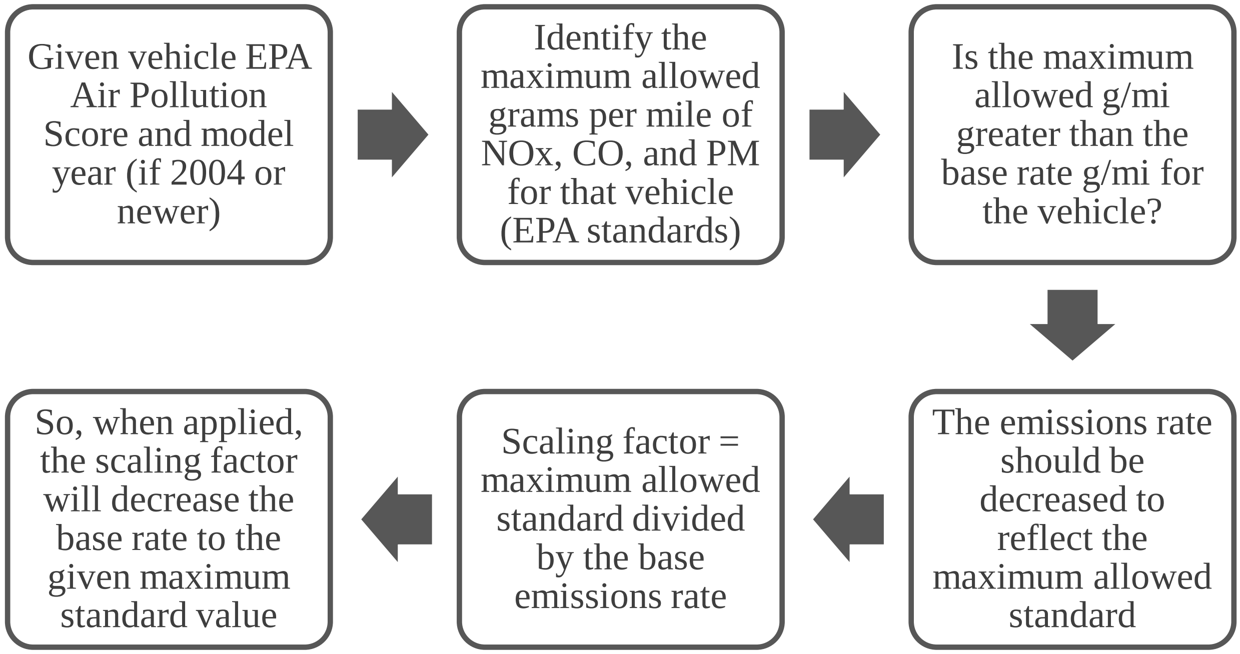


**Figure 14: Process to determine scaling factors for emissions rating.**

A similar process is used to determine the scaling factor for fuel efficiency that would be applied to $CO_2$ emission rates, with the exception that all vehicle years may be considered. The scaling factors for passenger cars and trucks resulting from this process are shown in Table 35.

**Table 35: 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 | 0.585567 | - | - |
| | | 8 | 0.878351 | - | - |
| | 2007-2009 | 10 | 0 | 0 | 0 |
| | | 9 | 0.377149 | - | - |
| | | 8 | 0.565724 | - | - |
| | | 7 | 0.754298 | - | - |
| | 2004-2006 | 10 | 0 | 0 | 0 |
| | | 9 | 0.143123 | 0.775183 | - |
| | | 8 | 0.214685 | 0.775183 | - |
| | | 7 | 0.286247 | 0.775183 | - |
| | | 6 | 0.500932 | - | - |
| | | 5 | 0.715617 | - | - |
| Passenger Truck | 2010+ | 10 | 0 | 0 | 0 |
| | | 9 | 0.110358 | - | - |
| | | 8 | 0.165538 | - | - |
| | | 7 | 0.220717 | - | - |
| | | 6 | 0.386254 | - | - |
| | | 5 | 0.551792 | - | - |
| | | 4 | 0.827688 | - | - |
| | 2007-2009 | 10 | 0 | 0 | 0 |
| | | 9 | 0.098783 | - | - |
| | | 8 | 0.148175 | - | - |
| | | 7 | 0.197566 | - | - |
| | | 6 | 0.345741 | - | - |
| | | 5 | 0.493916 | - | - |
| | | 4 | 0.740874 | - | - |
| | | 3 | 0.987832 | - | - |
| | 2004-2006 | 10 | 0 | 0 | 0 |
| | | 9 | 0.051579 | 0.552177 | - |
| | | 8 | 0.077369 | 0.552177 | - |
| | | 7 | 0.103158 | 0.552177 | - |
| | | 6 | 0.180527 | - | - |
| | | 5 | 0.257896 | - | - |
| | | 4 | 0.386844 | - | - |
| | | 3 | 0.515791 | - | - |
| | | 2 | 0.773687 | - | - |

*note: dashes are used when there is no appropriate scaling factor

Scaling factors for this measure are most applicable for NOx, while MOVES base rates are already below standards for most air pollution scores. This is expected, as the standards are given as the maximum allowable, so the emissions for the vehicle should not exceed that amount. Additionally, an air pollution score of ten represents a ‘zero-emission’ vehicle, so the scaling factors for all pollutants and years are zero for that score.

The scaling factors for fuel efficiency performance are calculated in a similar manner, comparing maximum allowed grams of $CO_2$e per mile to base rate $CO_2$ emissions. Unlike the air pollution score, this measure can apply to any vehicle model year, and does include many potential scaling factors. This measure would also be easier to adapt to heavy-duty vehicles, if the vehicle fuel efficiencies were known. Table 36 shows the scaling factors used for passenger cars and passenger trucks that would be applied to base rate $CO_2$ emissions. These scaling factors are based on the EPA-defined greenhouse gas score, which can be easily determined based on the vehicle’s fuel efficiency. A more direct relationship between fuel efficiency and scaling factors could be developed as well if desired.

**Table 36: $CO_2$ Scaling Factors Based on Greenhouse Gas Score**

| Vehicle Class | Vehicle Model Year | EPA Greenhouse Gas Score | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 |
| Passenger Car | 2011-2012 | 0.3932 | 0.4899 | 0.5866 | 0.6833 | 0.7800 | 0.8768 | 0.9735 | - | - |
| | 2010 | 0.4983 | 0.5950 | 0.6917 | 0.7885 | 0.8852 | 0.9819 | - | - | - |
| | 2009 | 0.5037 | 0.6014 | 0.6992 | 0.7970 | 0.8947 | 0.9925 | - | - | - |
| | 2007-2008 | 0.6418 | 0.7651 | 0.9096 | - | - | - | - | - | - |
| | 2004-2006 | 0.6317 | 0.7530 | 0.8952 | - | - | - | - | - | - |
| | 2000-2003 | 0.6342 | 0.7561 | 0.8989 | - | - | - | - | - | - |
| | 1996-1999 | 0.6447 | 0.7685 | 0.9137 | - | - | - | - | - | - |
| | 1992-1995 | 0.6511 | 0.7761 | 0.9227 | - | - | - | - | - | - |
| | 1988-1991 | 0.6448 | 0.7686 | 0.9138 | - | - | - | - | - | - |
| Passenger Truck | 2011-2012 | 0.3188 | 0.3972 | 0.4757 | 0.5541 | 0.6325 | 0.7109 | 0.7894 | 0.8678 | 0.9462 |
| | 2010 | 0.4041 | 0.4825 | 0.5609 | 0.6393 | 0.7178 | 0.7962 | 0.8746 | 0.9530 | - |
| | 2009 | 0.3761 | 0.4492 | 0.5222 | 0.5952 | 0.6682 | 0.7412 | 0.8142 | 0.8872 | 0.9602 |
| | 2007-2008 | 0.4793 | 0.5714 | 0.6793 | 0.7824 | 0.8888 | 0.9777 | - | - | - |
| | 2004-2006 | 0.4498 | 0.5362 | 0.6374 | 0.7342 | 0.8340 | 0.9174 | - | - | - |
| | 2000-2003 | 0.4552 | 0.5426 | 0.6450 | 0.7430 | 0.8440 | 0.9284 | - | - | - |
| | 1996-1999 | 0.4799 | 0.5721 | 0.6801 | 0.7834 | 0.8899 | 0.9789 | - | - | - |
| | 1992-1995 | 0.5173 | 0.6167 | 0.7332 | 0.8445 | 0.9593 | - | - | - | - |
| | 1988-1991 | 0.4962 | 0.5915 | 0.7033 | 0.8101 | 0.9202 | - | - | - | - |

*note: dashes are used when there is no appropriate scaling factor

It should be noted that, for the purposes of this framework, although the above scaling factors will decrease the baseline emissions rates to the maximum allowed standard for the vehicle, the vehicle’s emissions rate can still be scaled up due to hard acceleration/deceleration or highway speeds over 60 mph.  Thus, that performance is still accounted for even in low emission vehicles.

**Determining Performance Scores for Each Pollutant**

The above four performance measures translate into scaling factors, which are applied to the base emissions rates for the vehicle.  The basic setup for this system is shown in Figure 15.

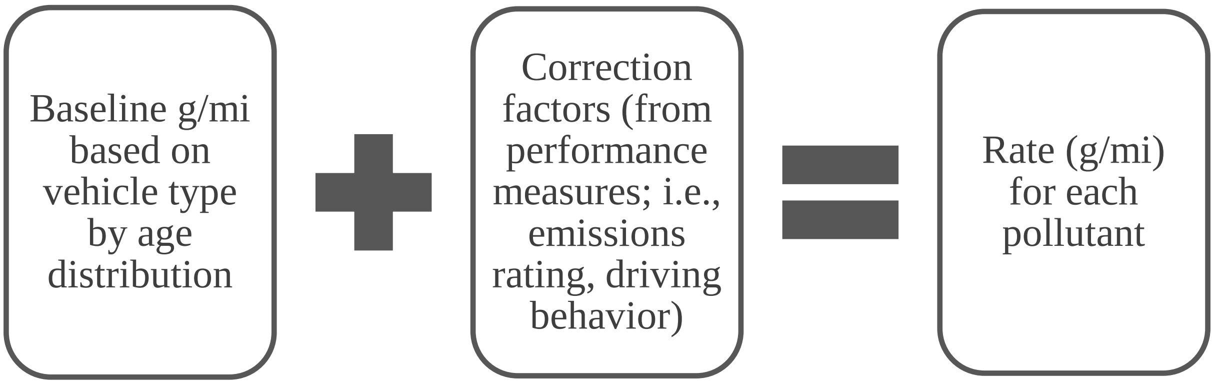


**Figure 15:  Basic method of determining pollutant rates.**

Base emissions rates are determined by vehicle class and model year.  Thus, the final emission rate for each pollutant can be determined as:

$$\begin{aligned} &Final\ Emission\ Rate\ \left(\frac{g}{mi}\right) \\ &\quad = Base\ Rate\ \left(\frac{g}{mi}\right) \times Scale\ Factor\ for\ Highway\ Speed\ Over\ 60\ mph \\ &\quad \times Scale\ Factor\ for\ Hard\ Acceleration\ and\ Deceleration \\ &\quad \times Scale\ Factor\ for\ Air\ Pollution\ or\ GHG\ Score \end{aligned}$$

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.

An additional step can be added in determining the final emissions rate.  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 emissions rate when traveling on a highway (over 50 mph for this report).  The percent of travel that occurs on a highway would likely also be tracked in order to calculate the percentage of travel that is over 60 mph.  To account for this, the following equation is used to determine the final emission rate:

$$Final\ Emission\ Rate\ \left(\frac{g}{mi}\right) = \left\{Base\ Rate\ \left(\frac{g}{mi}\right) \times Scale\ Factor\ for\ Hard\ Acceleration\ and\ Deceleration\ \times Scale\ Factor\ for\ Air\ Pollution\ or\ GHG\ Score\right\} \times \{(Scale\ Factor\ for\ Highway\ Speed\ Over\ 60\ mph \times Percent\ of\ Highway\ Travel) + Percent\ of\ Nonhighway\ Travel\}$$

This calculation will be used in Chapter 8.

Scoring the performance for each pollutant type requires comparing the individual's emission rate of each pollutant to the maximum and minimum emissions rates for the vehicle class. It was decided that scoring of passenger cars and passenger trucks would occur along the same scale for this project, as these vehicles have similar functions and drive cycles. For the other vehicle types, however, individual vehicles would only be compared to others within the vehicle class, as the other vehicle classes have fairly different functions and drive cycles.

*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 emissions rates for each pollutant type needed to be determined. For this project, many possible pollutant emissions rates were generated for a passenger car, combining different ages and scaling factors developed above. These possible rates were ordered from smallest to largest, and graphed along an x-axis representing performance scores from 0 to 100, with 100 being the highest (worst) emissions rate possible. Figure 16 shows the resulting distributions, with trend lines to illustrate the distribution shapes. Two different possible trend line shapes are shown for $CO_2$.

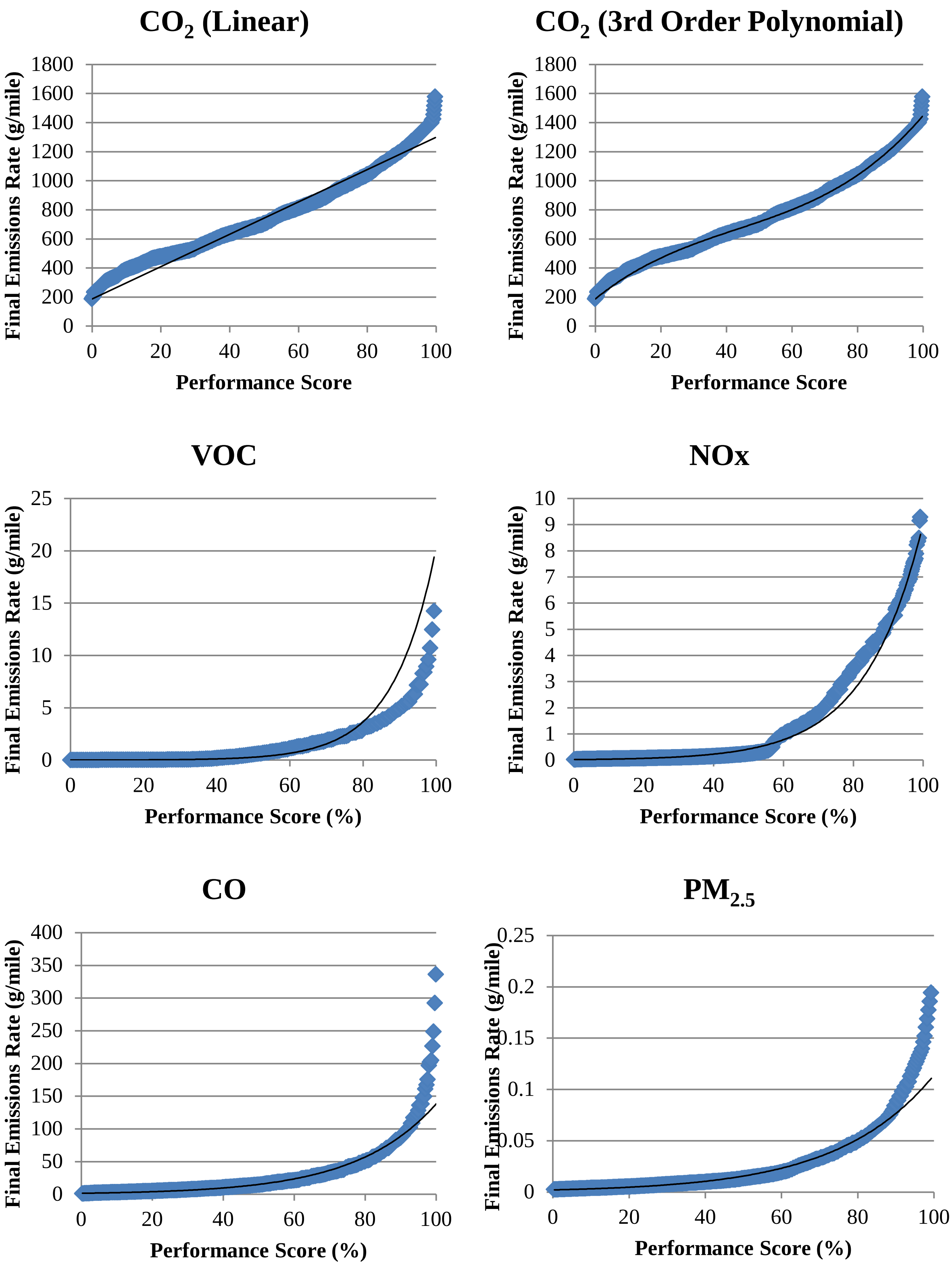


**Figure 16: Distribution of possible emissions rates and performance score values.**

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 project, the above distributions are assumed to be correct. 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 project we assume that the above distributions can be applied to passenger trucks as well. Finally, the best-fitting distribution for $CO_2$ would be a third-order polynomial, with an $R^2$ value of 0.9956. However, not enough data would be available to determine the variables for a passenger truck, so linear distribution is assumed for the purposes of this project, which also fits the data fairly well. The chosen distribution type for each pollutant is summarized below in Table 37, along with the equations and $R^2$ values of the trend lines used to determine the distribution shape.

**Table 37: Pollutant Distribution Shapes**

| Pollutant | Distribution | Equation | R-Squared Value |
|---|---|---|---|
| $CO_2$ | Linear | $y = 11.126x + 187$ | $R^2 = 0.9693$ |
| VOC | Exponential | $y = 0.0039e^{0.0857x}$ | $R^2 = 0.9691$ |
| NOx | Exponential | $y = 0.0197e^{0.0613x}$ | $R^2 = 0.9703$ |
| CO | Exponential | $y = 1.6731e^{0.0441x}$ | $R^2 = 0.9853$ |
| $PM_{2.5}$ | Exponential | $y = 0.0021e^{0.0397x}$ | $R^2 = 0.9849$ |

These distributions are used to determine performance scores for each pollutant by determining what score from a scale of 0 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, the variables used in the above distributions must be determined. For a linear distribution, as used for $CO_2$, the slope would be determined as:

$$Slope = \frac{Maximum\ Emissions\ Rate - Minimum\ Nonzero\ Emissions\ Rate}{100}$$

Then, an individual's performance score would be determined as:

$$Performance\ Score = \frac{Individual's\ Final\ Emissions\ Rate - Minimum\ Possible\ Rate}{Slope}$$

For an exponential equation, as used for VOC, NOx, CO, and $PM_{2.5}$, the variable is determined by:

$$Variable = \frac{\ln(\text{Maximum Emissions Rate}/\text{Minimum Nonzero Emissions Rate})}{100}$$

With that variable, an individual's performance score would be calculated as an exponential equation, based on the observed distribution shaped for these pollutants:

$$Performance\ Score = \frac{\ln(Individual's\ Final\ Emissions\ Rate / Minimum\ Nonzero\ Rate)}{Variable}$$

With the above equations, a performance score can be calculated for each pollutant. Again, it was decided that passenger cars and passenger trucks would be grouped together for scoring. Therefore, both vehicle classes are considered when determining the minimum and maximum possible emissions rates.

*Determining Final Performance Score*

A final overall performance can then be calculated based on performance for each pollutant. The final score for this project 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:

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

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 to 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 would be assigned by the agency using this framework, depending on what pollutants are of greater concern. In the example shown in Chapter 8, the weights shown in Table 38 are used.

**Table 38: Assumed Pollutant Weights for Examples**

| Pollutant | | | | | Sum |
|---|---|---|---|---|---|
| $CO_2$ | VOC | NOx | CO | $PM_{2.5}$ | |
| 0.12 | 0.12 | 0.34 | 0.12 | 0.3 | 1 |

The above possible weights give more importance to performance of NOx and $PM_{2.5}$ emissions. These pollutants were selected as 'more important' to consider as they are problematic in Texas.

## 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 is used to identify the base emission rates for the vehicle. The rates may then be increased based on aggressive driving behaviors. The results from the previous chapter are used to determine how much rates should increase based on the amounts of highway speed over 60 mph and of hard acceleration/deceleration. The air pollution score and fuel efficiency of the vehicle are used to decrease the emissions rates where applicable. An individual has greater immediate control over driving behaviors, while vehicle ownership changes are made in the long-term. Therefore, while vehicle age can negatively affect final performance, the other vehicle aspects (air pollution score and fuel efficiency) are only used to improve final performance at this time.

The final emissions rates for the individual vehicle are determined by scaling the base rates up and/or down based on performance measurement. A score between 0 and 100 is given for each pollutant based on the final emissions rate and the expected distribution. 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 chapter to determine how to apply pricing to the individual.

# CHAPTER 7: USE OF MEASURES IN ESTABLISHING A MILEAGE-BASED USER FEE SYSTEM

## Overview of Real-World Pricing

In order to determine what a good base fee rate would be, an investigation of various charges used in the real world or suggested in literature would be helpful. The ideal goal of this pricing scheme would be to induce a change in driver behavior, and thereby reduce emissions. 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 this pricing scheme could be to internalize some of the external environmental and health costs of emissions, so that actual road users help pay for the damage.

### *Real-World and Literature Examples*

As mileage-based pricing is still a fairly new concept; many of the pricing schemes in the real world involve other methods. Road pricing would include such things as toll roads and high occupancy toll lanes. The purpose behind such pricing generally involves revenue and congestion mitigation. Other examples of trying to control congestion include the congestion pricing utilized in central London. The London system charges drivers entering a certain area between 7:00 a.m. and 6:00 p.m., excluding some vehicle types such as motorcycles, buses, and some alternative fuel vehicles. The charge, currently £10, is only charged once per day regardless of the number of times a driver crosses into the tolling area (*81*). This type of fee is based on driving in the area, not on actual mileage driven within the area. The program has been fairly successful, both decreasing automobile traffic and improving traffic speeds and travel times. Other cities utilizing some sort of congestion pricing include Singapore and Oslo, Norway (*82*).

Another method of pricing currently of interest is a mileage-based system. However, this type of mileage-based pricing would not be implemented by the government, but by insurance companies. Pay-as-you-drive insurance programs are a potential method to encourage drivers to decrease their mileage. 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 (*83*). 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 (*84*). Additionally, PAYD insurance includes the possibility of pricing to influence other driver behavior. For example, aggressive driving or speeding would make a driver more likely to be involved in an accident. Insurance companies would desire to reduce risky behaviors as well, and could price accordingly. Indeed, Progressive Insurance does offer discounts up to 30 percent for good driving behavior, which they determine through a logging device used by a driver for a month (*85*). Algorithms used to determine pricing are trade secrets of these companies, but the idea is useful for mileage pricing in this project.

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 (*86*). The purpose is to internalize the wear and tear that heavy-duty vehicles impose on roadways, thus providing funding for maintenance. However, 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. The four emissions class categories are defined by the German government, and are included in vehicle registration certificates. In addition, certain particle reduction retrofits allow trucks to be charged at a lower level. Table 39 shows the current charges used, as of 2009, with the corresponding dollar per mile calculated (*87*). The conversion from euro to dollar is based on the conversion rate for January 10, 2012.

**Table 39: German Lkw-Maut Distance-Based Toll Rates for Heavy-Duty Vehicles**

| Emissions Class | Description | Number of Axles | Rate/ kilometer | Rate/ Mile |
|---|---|---|---|---|
| Category A | S5, EEV class 1 | up to 3 axles | 0.141 € | $ 0.290 |
| | | 4 axles or more | 0.155 € | $ 0.318 |
| Category B | S4, S3 with PMK 2, 3 or 4 | up to 3 axles | 0.169 € | $ 0.347 |
| | | 4 axles or more | 0.183 € | $ 0.376 |
| Category C | S3 without PMK, S2 with PMK 1, 2, 3 or 4 | up to 3 axles | 0.190 € | $ 0.390 |
| | | 4 axles or more | 0.204 € | $ 0.419 |
| Category D | S2 without PMK, S1 and vehicles not assigned to an emissions class | up to 3 axles | 0.274 € | $ 0.563 |
| | | 4 axles or more | 0.288 € | $ 0.592 |

Other distance-based charging schemes include recent pilot programs conducted by the Minnesota DOT (MnDOT) and the Oregon DOT (ODOT). An overview of various road charges is shown below in Table 40.

**Table 40: Overview of Various Tolls Either Suggested by Literature or Used in Real-World Applications**

| Toll/Rate | Location or Source | Description |
|---|---|---|
| 7¢/mile | Literature (*83*) | Approximate rate per mile from an average insurance premium of $850 per vehicle-year |
| 2¢/mile | Literature (*83*) | Approximate rate per mile from average registration and licensing fees of $250 annually |
| 5-25¢/mile | MnDOT (*84)* | Amount used in Minnesota DOT pilot project to determine driving behavior based on different PAYD insurance rates |
| 1.5¢/mile | Literature (*88*) | External local pollution cost |
| 20¢/mile | Literature (*84*) | Approximate mileage cost of fuel at $4 per gallon |
| $0.25-$8 | MnDOT (*89*) | Range of tolls for HOT lane on I-394 MnPass Express in Minnesota; adjusted to keep flow around 50-55 mph; updated based on detected densities and using lookup tables |
| $0.5-$4 | San Diego, CA (*90*) | Range of tolls for HOT lane on I-15 in San Diego, based on time of day; can be adjusted in response to traffic conditions |
| £10/day ($16) | London, UK (*87*) | London congestion charge within the CBD on weekdays between 7am and 6pm; with exemptions such as for green vehicles, taxis, and residents |
| 0.141-0.288 €/km (29.0 - 59.2¢ /mile) | Germany (*91*) | 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 (*92*) | 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 (*93*) | Mileage rates examined for air quality responses within a cordon zone for Leeds, UK |
| 0.6-3.3¢/mile | Literature (*94*) | Mileage rates to replace fuel tax based on average fuel efficiency of 18 vehicle classes |
| 7¢Can/km (11.23¢ /mile) | Literature (*95*) | 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.

*Externality Cost of Emissions*

One potential method of determining user fees would be to charge drivers for the damage of the pollutants they emit. In other words, drivers would have to pay for the air quality externality that results from their travel. Damages caused by pollutants include effects on human health and effects on the environment. For example, exposure to $PM_{2.5}$ can aggravate or cause respiratory problems. Environmental costs could include ecological damage, crop loss, and infrastructure damage. Again, Appendix B lists many health and environmental effects of different pollutants. Calculating the actual unit cost for each pollutant type, however, is difficult. The relationship between emissions and resulting damages is not concrete, and developing costs for damages may not be concrete either. Determining the exact number of health cases that were the direct result of exposure to a certain pollutant would be practically impossible. The costs related to illnesses depend on what is accounted for. Direct costs, such as treatment costs, are more straightforward; while indirect costs, such as lost wages, are more difficult to determine. There are also differences across the world of the perceived monetary value of a human life. Putting a price on ecological damage is also dependent on human values of such damages, which certainly vary (*96*). In addition, the long-term effects of greenhouse gas emissions on the environment are not generally understood, and these effects are not limited only to a small area.

However, damage costs can be modeled to determine a general relationship. For example, the European Commission ExternE project has worked extensively to try to determine such costs. The methodology they developed, called the 'Impact Pathway Approach' has been referenced and used across the world (*97*). In simple terms, this approach models the relationship between transportation and social health cost as follows:

- Emissions factor—relate traffic to emissions;
- Exposure factor—relate emissions to population exposure;
- Damage factor—relate population exposure to health damages; and
- Monetary valuation—relate health damages to social costs (*98*).

In this case, exposure factors were estimated using pollution dispersion models and population densities. Damage factors were estimated using dose-response relationships. Dose-response functions relate deaths (mortality) and illnesses (morbidity) to pollutant exposure (*96*). However, using this methodology to develop local damage costs would be far outside the scope of this project.

On the other hand, a basic idea of estimated externality costs is useful. As an example, the following costs in Table 41 represent the value of a change for several pollutant types (*99*). The values were derived by the National Highway Traffic Safety Administration (NHTSA) based on EPA estimates.

**Table 41: NHTSA Estimated Damage Costs of Emissions**

| Pollutant | Damage Cost (in 2007 $) | Damage Cost (in 2007 ¢) |
|---|---|---|
| CO | $ - /ton | ¢ - /gram |
| VOC | $1,700/ton | ¢0.1874/gram |
| NOx | $4,000/ton | ¢0.4409/gram |
| PM | $168,000/ton | ¢18.5188/gram |
| $SO_2$ | $16,000/ton | ¢1.7637/gram |
| $CO_2$ (U.S. domestic value) | $2/metric ton | ¢0.0002/gram |
| $CO_2$ (mean global value) | $33/metric ton | ¢0.0033/gram |

The table also shows the damage cost converted to cents per gram of emissions. These values could be used to obtain a mileage-based cost for each pollutant, if the vehicle's emissions rates are known, calculated as:

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

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 the base emissions rates obtained from MOVES. For this example, the U.S. domestic value of $CO_2$ damage was used. Table 42 shows the results.

**Table 42: 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** |

As Table 42 shows, the fee related to emissions damage cost in cents per mile is fairly low. However, these values are fairly consistent with the suggested external local pollution cost of 1.5 cents per mile found in literature (*88*). The rate per mile could greatly increase with consideration of performance measures. Thus, if the desired goal of pricing is to pay for the damage caused by pollutant emissions, the above method could be applied to the pricing framework.

*Application to Project*

For this project, the primary goal with pricing is to influence driver behavior to an extent that emissions are lowered. Of particular interest is the Minnesota PAYD insurance pilot project, which utilized a range of mileage rates to determine driver response. In this pilot project, the driving of 30 households was monitored without pricing during the experiment, as the control group (*100*). The other 100 households involved were monitored both without pricing for two months, with pricing applied to 50 households for the next three months, and with pricing applied to the other 50 households the third time period of three months. 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 (*101*). These data were analyzed, and results are shown in Figure 17.

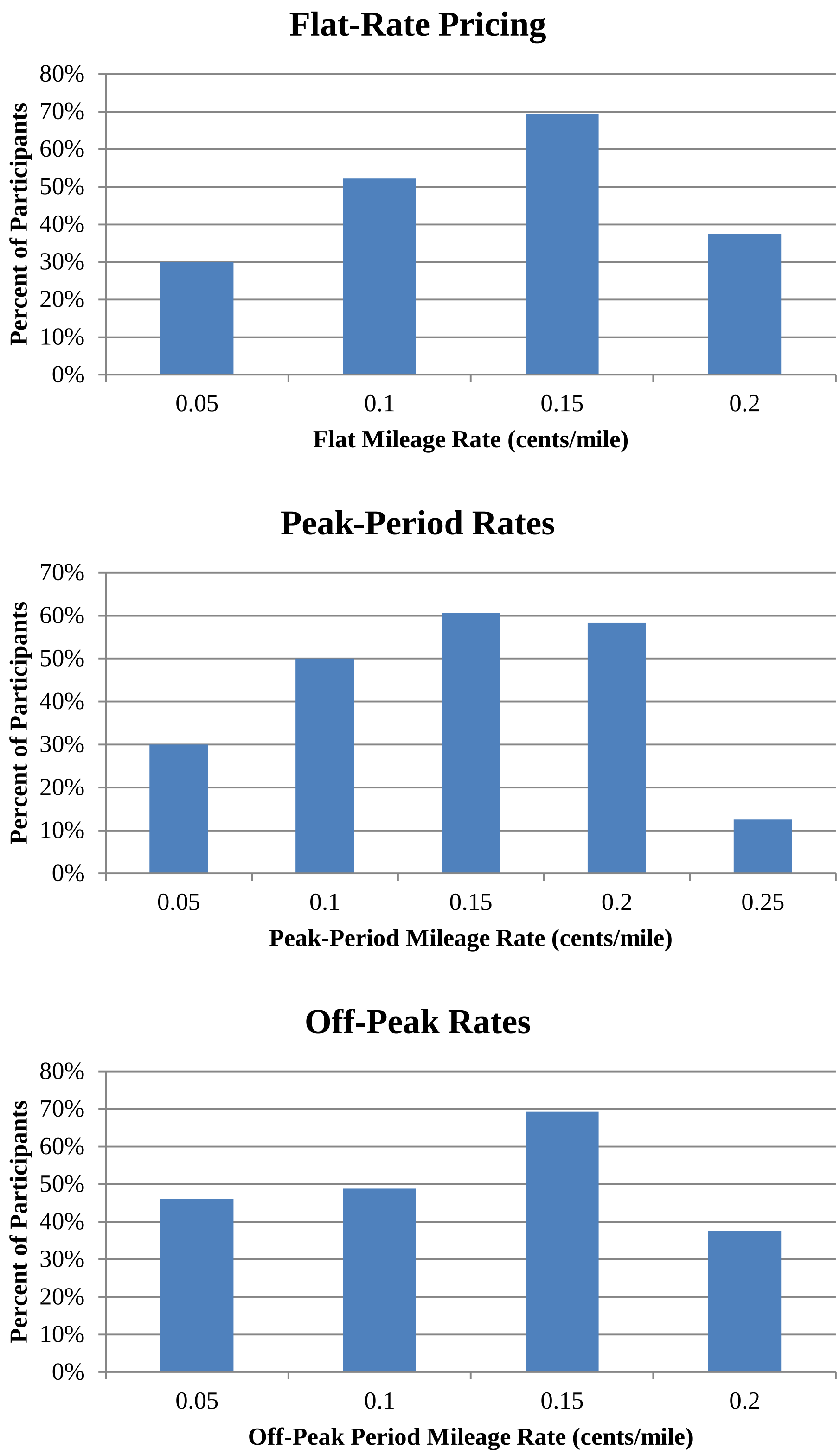


**Figure 17: Percent of participants that decreased mileage from the Minnesota PAYD experiment results.**

The above graphs show that the largest percentage of participants that decreased their mileage occurred for participants priced at 15 cents per mile.  From this, we assume 15 cents per mile as a good threshold value for influencing driver behavior.  Thus, for the purposes of this project, we will assume 15 cents as the base fee for our pricing scheme.

**Pricing System**

Performance measurement, as discussed in the previous chapter, is used to determine if the base mileage fee should be increased and by what amount.  It is desirable to consider how the individual's performance compares to others in the system.  The simplest method, which will be used in this report, is to calculate the ratio of the individual's final performance score to the average across the system for that vehicle class, or passenger cars and passenger trucks together as a group.  This ratio can then be multiplied with the base fee.  Thus, if an individual performs better than average, they pay less; and if they perform worse than average, they pay more.  This may not be the ideal method, as it allows the potential for an individual to be several times worse than average and significantly increase their mileage rate.  However, it may be desirable to charge low-performing drivers very high rates.  A maximum increase or decrease could be defined.  Other functions could be used to compare the two performance scores as well, at the discretion of the agency using the system.

Additionally, it would be desirable to compare different vehicle classes to an extent. Individual performance only takes into account other vehicles of the same class, or the passenger vehicle group.  However, heavy-duty vehicles certainly emit more than lighter vehicles, which should be accounted for.  Figure 18 shows how many times greater pollutant emissions are on average comparing each vehicle type to passenger cars.

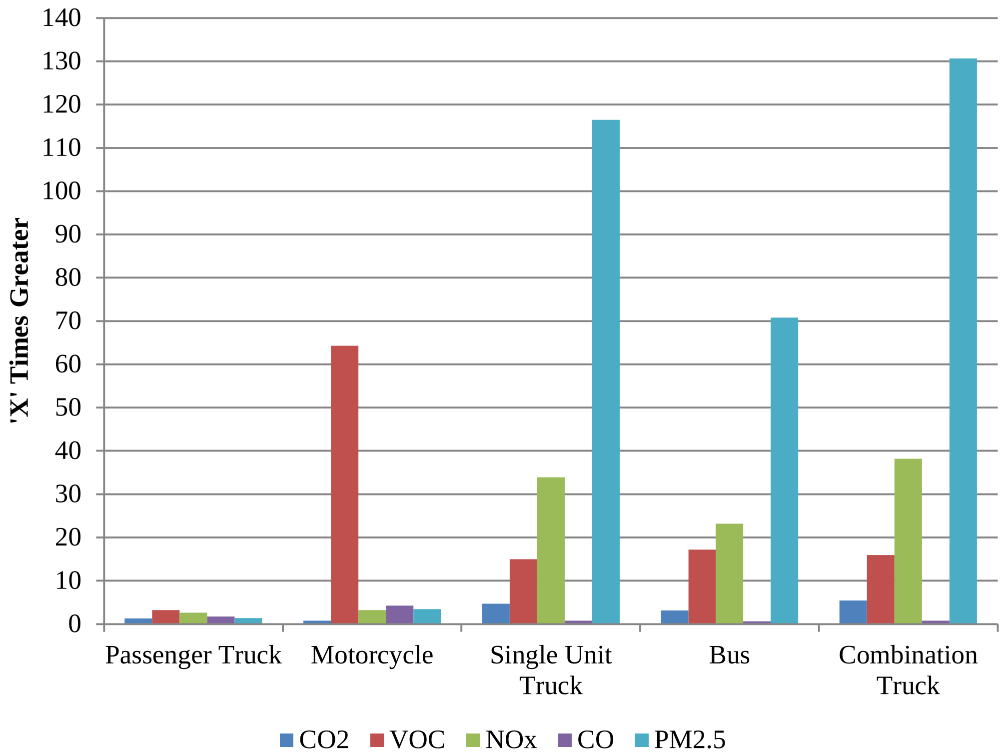


**Figure 18: Illustration of how other vehicle emissions rates compare to passenger cars.**

As shown, passenger truck emissions are not much greater than passenger car emissions, which is another reason for grouping the two classes together for the purposes of performance scoring. Motorcycles are fairly similar, except for significantly higher VOC emissions. Heavy-duty vehicles have typically much higher emissions levels, with the exception of CO. However, the amount that the mileage fee is increased based on vehicle type is up to the agency. Despite the fact that heavy-duty vehicles emit approximately 30 times more pollutants than passenger cars, it is unlikely that heavy-duty vehicles would be charged mileage fees that are 30 times higher. For the purposes of this project, we will simply assume that for heavy-duty vehicles the base mileage fee is 30 cents per mile, or twice what light-duty vehicles pay.

Finally, since mileage occurring during certain times and places is of interest in the performance measurement framework, the fee applied to this mileage may be different. 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 project, this basic calculation for determining the fee per mile assessed to the user is used:

$$\mathit{Final\ Fee\ for\ Mileage\ Within\ Specific\ Times/Locations}\ \left(\frac{\$}{mi}\right)$$
$$= \mathit{Base\ Fee\ for\ Class}\ \left(\frac{\$}{mi}\right) \times \frac{\mathit{Individual\ Performance\ Score}}{\mathit{Average\ Score\ for\ Vehicle\ Class}}$$
$$\times\ \mathit{Increase\ Factors\ for\ Time\ and\ Location}$$

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

**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 the pricing in place. Thus, system-wide performance should be tracked over time to determine changes over time. Changes in individual performance could also be tracked over time, although the results would likely need to be aggregated to be useful for study. Ambient air quality values could be useful as well in determining if air quality itself is actually improving. If the desired change is not occurring at the current pricing level, pricing may need to be increased to induce the desired behavior change. Therefore, the system must provide some sort of feedback that will allow pricing to be adjusted to attempt to reach the desired goal.

*Dynamic Pricing*

Dynamic toll pricing in literature and in practice can provide an example of adjusting the price to obtain a desired outcome. The goal with dynamic tolling is typically to adjust the toll rate in real-time based on traffic conditions in order to mitigate congestion. To that end, lane occupancy, density, or speed would be likely candidates to track to determine real-time conditions. Hopefully, then, the toll rate would change to keep speed, density, or occupancy at a desired level. For example, dynamic pricing is used on HOT lanes on I-394 in Minnesota, with the capability of adjusting the toll rate every three minutes (*102*). Toll rates are adjusted with any detected density change, based on 'lookup' tables, so that free-flow speed can be maintained.

One suggested method of determining toll rates involves gradually learning about users' willingness to pay by monitoring flows at different toll rates over time (*103*). This willingness to pay could then be used, along with approaching traffic flow, to determine optimum toll rate. Alternatively, the problem could be approached with algorithms, computing travel costs based on toll rates and travel time, updating flows on links, and repeating with different toll rates until an objective function is met (*104*).

Based on these examples, determining the optimum mileage fee to achieve desired air quality objectives will likely take several iterations. Adjusting base mileage fees over several pay periods will help reveal how drivers respond to price by changing their behavior. Fees can eventually be set to achieve optimum change in behavior; particularly mileage, which will reduce emissions by a desired amount.

*Transportation Elasticity*

Prices associated with transportation influence travel behavior. The cost of travel certainly includes tolls and gasoline taxes. But less tangible costs associated with travel, such as travel time and risk, are also important. Changes in the costs 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 -0.5, then a 1-percent increase in the gas tax will result in a 0.5-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 typically considered to be inelastic. However, even with relatively low elasticities, pricing measures that affect all travel can have an impact on travel behavior (*105*).

In transportation, arc elasticity is most frequently used (*106*). Arc elasticity is calculated as:

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

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:

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

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

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

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, Figure 19 shows ranges associated with different types of price changes (*106*).

| Estimated Component | Fuel Price | Income | Taxation (Other than Fuel) | Population Density |
|---|---|---|---|---|
| Car Stock (vehicle ownership) | -0.20 to 0.0 (-0.1) | 0.75 to 1.25 (1.0) | -0.08 to -0.04 (-0.06) | -0.7 to -0.2 (-0.4) |
| Mean Fuel Intensity (fuel efficiency) | -0.45 to -0.35 (-0.4) | -0.6 to 0.0 (0.0) | -0.12 to -0.10 (-0.11) | -0.3 to -0.1 (-0.2) |
| Mean Driving Distance (per car per year) | -0.35 to -0.05 (-0.2) | -0.1 to 0.35 (0.2) | 0.04 to 0.12 (0.06) | -0.75 to 0.0 (-0.4) |
| Car Fuel Demand | -1.0 to -0.40 (-0.7) | 0.05 to 1.6 (1.2) | -0.16 to -0.02 (-0.11) | -1.75 to -0.3 (-1.0) |
| Car Travel Demand | -0.55 to -0.05 (-0.3) | 0.65 to 1.25 (1.2) | -0.04 to 0.08 (0.0) | -1.45 to -0.2 (-0.8) |

*Summarizes various studies. Numbers in parenthesis indicate original authors' "best guess" values.*

**Figure 19: Example ranges of estimated elasticity values.**

Unfortunately, not much information is known about the relationship between price changes and driving behavior. In addition, costs do affect decisions about what type of vehicle to purchase, but changes in vehicle ownership occur slowly over time. The most applicable elasticity values relate to mileage. For example, 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 to mileage fees, which are proportional to mileage as well.

*Application to Project*

For this project, 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. Unfortunately, elasticity values related to other vehicle activity are not generally known. Vehicle choice for the long-term does correspond to recurring costs; however, change in the vehicle fleet occurs slowly over time. Since a direct relationship between driving behavior and vehicle choice is not known, decreasing mileage will be the desired outcome of the project framework. With an idea of emissions rates for each user, changes in mileage will directly correspond to changes in total pollutants emitted by each vehicle. For example, a 5-percent decrease in mileage would result in a 5-percent decrease in total emissions, since emissions rates are multiplied by mileage to determine total emissions.

Using the above elasticity value, base mileage rates can be adjusted as:

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

The actual changes in mileage in response to price changes can be tracked over time to help calibrate the actual elasticity. Price can continue to be adjusted until set air quality goals are reached. An example goal could be to reduce total NOx by 5 percent. Figure 20 illustrates the basic feedback loop suggested for this project.

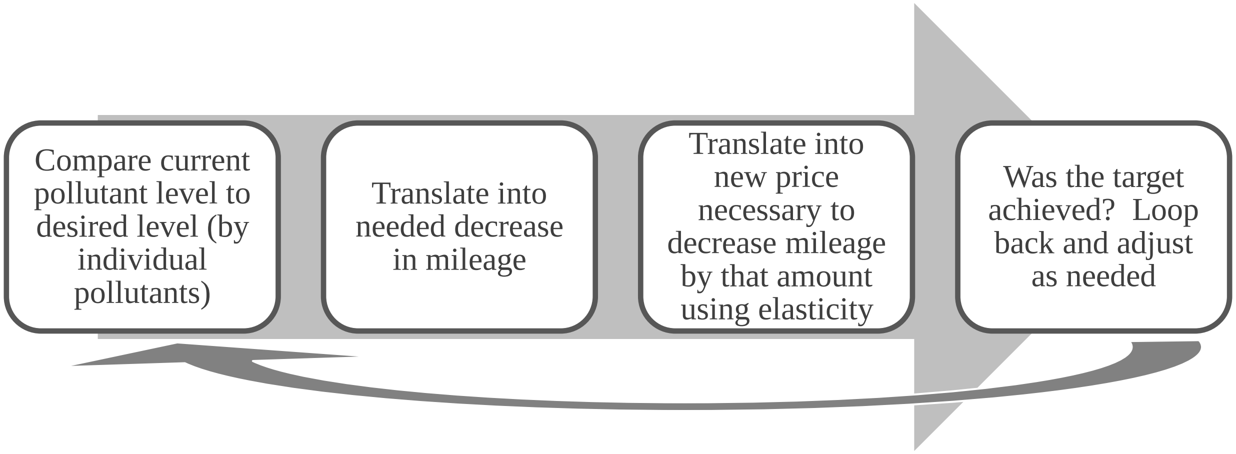


**Figure 20: Illustration of feedback loop.**

Of course, different drivers will respond differently to price changes, which emphasize the need for ongoing adjustments.

**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 project, a fairly simple calculation for the fee charged to an individual is suggested; however, different functions could be used. The base fee was selected as likely to induce a change in mileage driven. Any desired base fee could be used, based on the preference or needs of an agency using this system. 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 all vehicle classes separately rather than for light-duty vehicles and heavy-duty vehicles only. However the base fee is selected, an individual's overall performance score and the average score across the vehicle class are used to increase or decrease the base rate to the final amount charged to the individual.

Finally, some sort of feedback loop should be included in any pricing that is intended to achieve a goal. In this case, 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 chapter using actual real-world travel data.

# CHAPTER 8: EXAMPLE APPLICATION OF SYSTEM

## Overview

Actual travel data from two different vehicles are used in this example to illustrate how the performance measurement and pricing frameworks are used. Several assumptions are made, including:

- Vehicle characteristics of age, emissions rating, and fuel efficiency;
- Percent overlap of freeway miles and peak-hour miles;
- Facilities of interest to charge at a higher mileage fee;
- Importance factors applied to each pollutant type to calculate a final aggregated performance measure;
- 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 used in this example.

## 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 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. Mileage occurred within the area surrounding Austin, Texas. Data collected for the passenger car occurred between March 19, 2011, and March 31, 2011. For the passenger truck, data were obtained 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 21 illustrates the trips made by the passenger car.

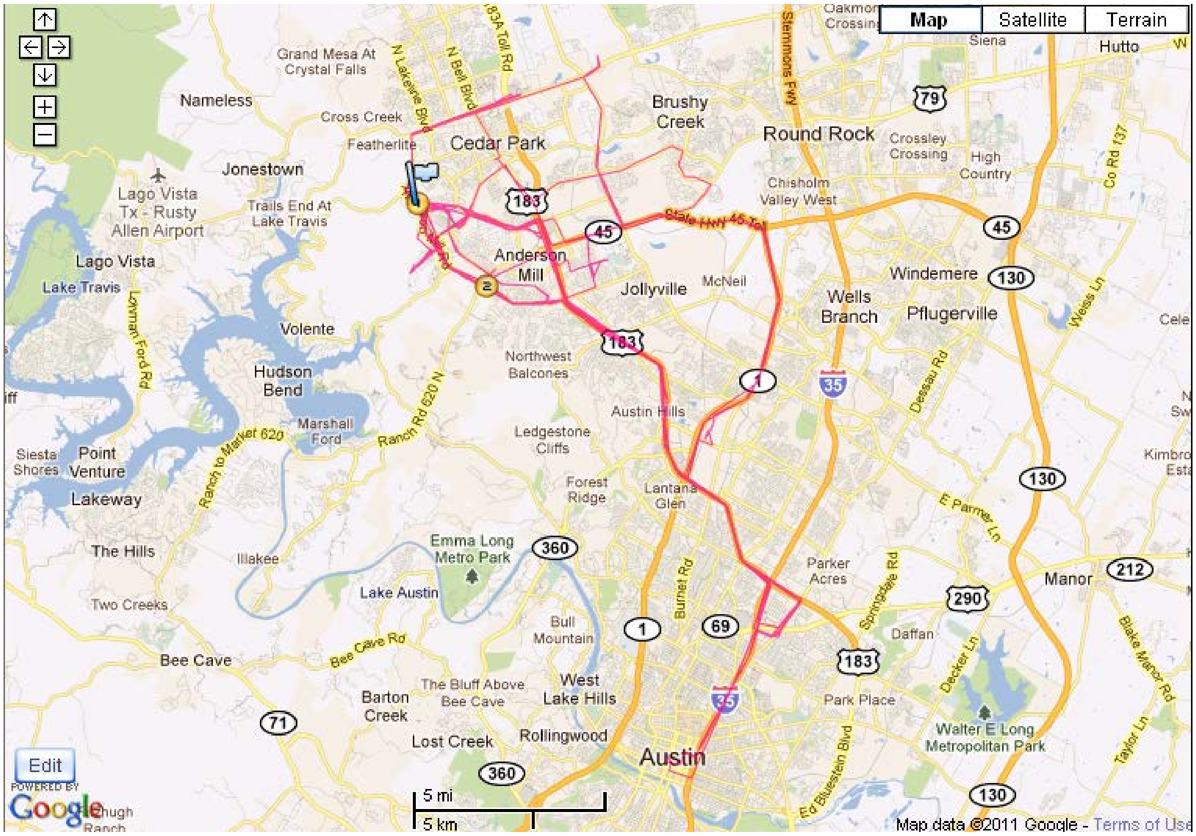

**Figure 21: Passenger car routes.**

Similarly, Figure 22 shows the trips made by the passenger truck.

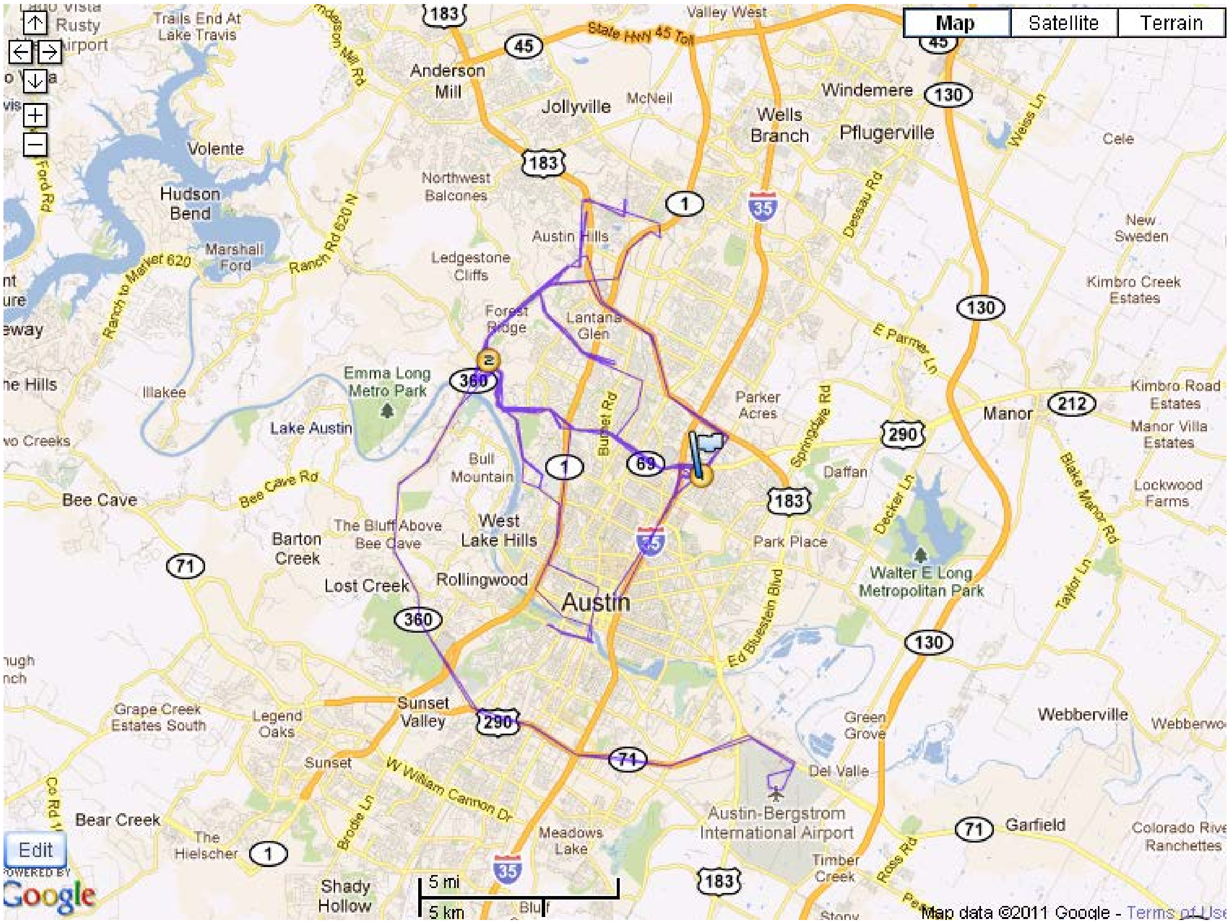

**Figure 22: Passenger truck routes.**

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:

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

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.

The mileage occurring during peak hours was estimated from the data. Distance traveled each second was calculated as:

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

Distances that occurred during peak hours were totaled 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. It was assumed that mileage traveled on Interstate 35 and on Mopac Expressway was of particular interest for pricing. The mileage that occurred on these facilities was estimated visually from the above maps, based on the number of trips observed.

All the data were analyzed to obtain the statistics necessary for evaluating performance. The results are summarized in Table 43 below.

**Table 43: Overview Statistics of Example GPS Data**

| Statistic | Passenger Car | Passenger Truck |
|---|---|---|
| Total Travel Time | 31.52 hours | 28.13 hours |
| Percent Highway Travel | 0.2287 | 0.2059 |
| Percent Highway Travel >60 mph | 0.7932 | 0.7872 |
| Percent ‘Hard’ Acceleration/ Deceleration | 0.1645 | 0.1630 |
| Total Mileage | 714.88 miles | 553.26 miles |
| Time Traveled during Peak Hours | 9.35 hours | 12.26 hours |
| Total Mileage during Peak Hours | 161.67 miles | 277.14 miles |
| Mopac and I-35 Miles | 40.7 miles | 11.1 miles |

The above data were used to evaluate the performance measures developed in this report. The performance measures involving mileage are fulfilled in the table above, with mileage during peak hours and on certain facilities differentiated. Whether mileage on the specified facilities occurred during peak hours or not could not be determined. Thus, for this project we assume that half of the freeway mileage occurs during peak hours. In other words, half of the mileage traveled on I-35 and Mopac was assumed to occur during peak hours, and half during non-peak hours, for illustrative purposes only.

Finally, specific information on the model and age of the vehicles observed was not provided. The passenger car was assumed to be a 2006 model, with an EPA air pollution score of 7 and an average fuel efficiency of 27 miles per gallon of gasoline. The passenger truck was assumed to be a 2006 model, with an EPA air pollution score of 5 and an average fuel efficiency of 25 miles per gallon of gasoline.

### Performance Measurement Quantification

The above information, whether assumed or obtained from data analysis, is used to determine scaling factors that are applied to base emissions rates. Vehicle class and age affect what the base emissions rates are for the individual. Performance is used to determine how much worse or better an individual’s emissions are from the base rate.

*Passenger Car*

Performance on the first measure is simply the total vehicle mileage during the time period, or 714.88 miles. For the second measure, Table 44 illustrates performance, which is the allocation of mileage.

**Table 44: Passenger Car Mileage Allocation**

| Area | Time of Day | | Area Total |
|---|---|---|---|
| | Peak | Off-Peak | |
| I-35 and Mopac | 20.35 | 20.35 | 40.7 |
| All other areas | 141.32 | 532.86 | 674.18 |
| **Time of Day Total** | 161.67 | 553.21 | **714.88** |

Vehicle class (passenger car) and vehicle model year (2006) were used to determine base emissions rates for the vehicle, which are:

- 476.155 grams per mile of $CO_2$;
- 0.0933 grams per mile of VOC;
- 0.6782 grams per mile of NOx;
- 4.9016 grams per mile of CO; and
- 0.0039 grams per mile of $PM_{2.5}$.

Performance on other measures affects the factors used to scale base emissions rates up or down. The individual's performance and resulting scaling factors are illustrated below in Table 45.

**Table 45: Passenger Car Performance and Scaling Factors**

| Performance on Measures: | | Emissions Effect: Scaling Factors | | | | | |
|---|---|---|---|---|---|---|---|
| | | Symbol | $CO_2$ | VOC | NOx | CO | $PM_{2.5}$ |
| Air Pollution Score | 7 | ERF | - | - | 0.2863 | 0.7752 | 1 |
| Fuel Efficiency | 27 | FEF | 0.8952 | - | - | - | - |
| Percent Highway Speed above 60 mph | 0.7932 | HSF | 1.0854 | 2.3243 | 1.8208 | 2.4371 | 1.2204 |
| Percent Aggressive Acceleration/ Deceleration | 0.1645 | AAF | 1.2777 | 1 | 1.1230 | 1 | 1.1656 |

Additionally, 22.87 percent of the travel occurred above highway speeds, which affects how much the scaling factors from the highway speed measure affect the emissions rate.

*Passenger Truck*

As with the passenger car, performance on the first measure is simply the total vehicle mileage during the time period, or 714.88 miles. For the second measure, Table 46 illustrates performance.

**Table 46: Passenger Truck Mileage Allocation**

| Area | Time of Day | | Area Total |
|---|---|---|---|
| | Peak | Off-Peak | |
| I-35 and Mopac | 5.55 | 5.55 | 11.1 |
| All other areas | 271.59 | 270.57 | 542.16 |
| **Time of Day Total** | 277.14 | 276.12 | **553.26** |

Vehicle class (passenger truck) and vehicle model year (2006) were used to determine base emissions rates for the vehicle, which are:

- 671.450 grams per mile of $CO_2$;
- 0.0707 grams per mile of VOC;
- 0.3878 grams per mile of NOx;
- 3.8031 grams per mile of CO; and
- 0.0044 grams per mile of $PM_{2.5}$.

The passenger truck had lower emissions rates of VOC, NOx, and CO than the passenger car, despite being in the same age category. However, emissions of $CO_2$ and $PM_{2.5}$ were higher than for the passenger car, likely due to differences between the two vehicle classes. Performance on other measures affects the factors used to scale base emissions rates up or down. The individual's performance and resulting scaling factors are illustrated below in Table 47.

**Table 47: Passenger Truck Performance and Scaling Factors**

| Performance on Measures: | | Emissions Effect: Scaling Factors | | | | | |
|---|---|---|---|---|---|---|---|
| | | Symbol | $CO_2$ | VOC | NOx | CO | $PM_{2.5}$ |
| Air Pollution Score | 5 | ERF | - | - | 0.2579 | 1 | 1 |
| Fuel Efficiency | 25 | FEF | 0.7342 | - | - | - | - |
| Percent Highway Speed above 60 mph | 0.7872 | HSF | 1.1181 | 2.0078 | 1.1903 | 1.6084 | 1.2251 |
| Percent Aggressive Acceleration/ Deceleration | 0.1630 | AAF | 1.2395 | 1.3394 | 1.1411 | 1 | 1 |

Additionally, 20.59 percent of the travel occurred above highway speeds, which affects how much the scaling factors from the highway speed measure affect the emissions rate.

*Application of Scaling Factors to Calculate Final Performance Score*

Scaling factors are applied to the individual's base emissions rates to obtain final emissions rates as:

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

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/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.

Based on minimum and maximum possible emissions rates for similar vehicle types, the performance score out of 100 for $CO_2$ is calculated as:

$$Performance\ Score = \frac{Individual's\ Final\ Emissions\ Rate - Minimum\ Possible\ Rate}{Slope}$$

with slope determined by:

$$Slope = \frac{Maximum\ Emissions\ Rate - Minimum\ Nonzero\ Emissions\ Rate}{100}$$

For the other four pollutants, which are based on exponential distributions rather than linear distributions, the performance score is calculated as:

$$Performance\ Score = \frac{\ln(Individual's\ Final\ Emissions\ Rate / Minimum\ Nonzero\ Rate)}{Variable}$$

with the variable term calculated as:

$$Variable = \frac{\ln(\text{Maximum Emissions Rate}/\text{Minimum Nonzero Emissions Rate})}{100}$$

These equations were discussed more extensively in Chapter 6.  Again, with an actual system in place, the real-world distributions of emissions rates could be better determined by observing all individuals across the system in each vehicle class.  This would allow for better computation of actual performance relative to distributions that are possible rather than theoretical.  However, for this example, the above distributions are assumed to be accurate.  Also, although for some pollutants the minimum emissions rate may be zero, this value cannot be used with the natural log function.  If the vehicle had zero emissions for a particular pollutant, a performance score of 0 out of 100 would be given, which is the best possible score.

Since it was decided to group passenger cars and passenger trucks together for scoring, a combination of maximum and minimum possible emission rates from both vehicle types were used.  Table 48 shows these values and the resulting slope or variable used for calculation of performance score.

**Table 48: Distribution Values for Passenger Vehicle Group**

| Values for Group of Passenger Cars and Trucks | Pollutant | | | | |
|---|---|---|---|---|---|
| | **$CO_2$** | **VOC** | **NOx** | **CO** | **$PM_{2.5}$** |
| Maximum Possible Emissions Rate | 2007.634 | 30.1837 | 10.7484 | 284.6505 | 0.3515 |
| Minimum Possible Non-Zero Emissions Rate | 125.000 | 0.0039 | 0.0200 | 0.8774 | 0.0022 |
| Slope/Variable | 18.826 | 0.0897 | 0.0629 | 0.0578 | 0.0508 |
| Assumed Distribution | Linear | Exponential | Exponential | Exponential | Exponential |

The above values will be used to calculate the performance score for each pollutant type for both the passenger car and the passenger truck in this example.

Finally, final performance score is aggregated from performance on each pollutant, based on assumed importance weights applied to each pollutant. This allows some pollutants to be given more consideration if desired. For example, in this example, emissions of NOx and $PM_{2.5}$ are considered of primary importance, thus are given more consideration when calculating the final score. The performance score for each pollutant and total performance score for the passenger vehicle are shown below in Table 49.

**Table 49: Passenger Car Performance Scores**

| For Example Passenger Car: | Pollutant | | | | |
|---|---|---|---|---|---|
| | **$CO_2$** | **VOC** | **NOx** | **CO** | **$PM_{2.5}$** |
| Base Rate in g/mi | 476.155 | 0.0933 | 0.6782 | 4.9016 | 0.0039 |
| New Rate in g/mi | 555.228 | 0.1215 | 0.2589 | 5.0483 | 0.0048 |
| **Performance Score (out of 100)** | **22.8525** | **38.4868** | **40.7327** | **30.2628** | **15.4349** |
| Assumed Pollutant Importance Weight | 0.12 | 0.12 | 0.34 | 0.12 | 0.30 |
| **Final Performance Score (out of 100)** | **29.4718** | | | | |

Similarly, the performance scores for the passenger truck are shown in Table 50.

**Table 50: Passenger Truck Performance Scores**

| For Example Passenger Truck: | Pollutant | | | | |
|---|---|---|---|---|---|
| | **$CO_2$** | **VOC** | **NOx** | **CO** | **$PM_{2.5}$** |
| Base Rate in g/mi | 671.450 | 0.0707 | 0.3878 | 3.8031 | 0.0044 |
| New Rate in g/mi | 627.566 | 0.1166 | 0.1191 | 4.3323 | 0.0046 |
| **Performance Score (out of 100)** | **26.6948** | **38.0235** | **28.3772** | **27.6174** | **14.7868** |
| Assumed Pollutant Importance Weight | 0.12 | 0.12 | 0.34 | 0.12 | 0.30 |
| **Final Performance Score (out of 100)** | **25.1646** | | | | |

The final calculated performance scores are now used to determine pricing.

**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. As average performance scores for each vehicle class are not known, we assume an average score of 32 out of 100 for both the passenger car and the passenger truck. Again, we assume that the base mileage fee is $0.15 per mile for light-duty vehicles, and $0.30 per mile for heavy-duty vehicles, although we are not evaluating heavy-duty vehicles in this example. Although many functions could be used to calculate how performance affects the mileage fee charged to the individual, this example assumes the simple function of:

$$New\ Mileage\ Fee\left(\frac{\$}{mi}\right) = Base\ Mileage\ Fee\left(\frac{\$}{mi}\right) \times \frac{Individual\ Performance\ Score}{Average\ Score\ for\ Vehicle\ Class}$$

The passenger car performs somewhat worse than the assumed system average, with a final performance score of 29.4718. Therefore, the new base rate assessed to this individual is $0.1381 per mile rather than fifteen cents. The passenger truck performs better than the assumed average with a final score of 25.1646, so will be charged less at $0.1180 per mile.

In addition, we desire mileage that occurs on certain facilities (I-35 and Mopac) and during certain times (peak-hours) to be charged at a higher rate. We assume an increase factor of 1.3 for mileage that occurs during peak hours and an increase factor of 1.1 for mileage that occurs on the above facilities. If mileage occurs on these facilities and during peak hours, both factors would apply, so the mileage fee would increase by 1.43. The final rates applied to mileage for the two vehicle types are shown in Table 51.

**Table 51: Final Mileage Fees**

| Mileage Type | Fee ($/mile) | |
|---|---|---|
| | Passenger Car | Passenger Truck |
| Mileage on I-35 and Mopac during Peak Hours | 0.1976 | 0.1687 |
| Peak-Hour Mileage Off Facility | 0.1796 | 0.1533 |
| Mileage on I-35 and Mopac during Off-Peak Hours | 0.1520 | 0.1300 |
| Non-Peak and Off Facility Mileage | 0.1381 | 0.1180 |

Based on the mileage given above for each vehicle type, the total amount paid is shown in Table 52.

**Table 52: Final Charge Assessed to User**

| Mileage Type | Passenger Car | Passenger Truck |
|---|---|---|
| Mileage on I-35 and Mopac during Peak Hours | $4.02 | $0.94 |
| Peak-Hour Mileage Off Facility | $25.38 | $41.65 |
| Mileage on I-35 and Mopac during Off-Peak Hours | $3.09 | $0.72 |
| Non-Peak and Non-Facility Mileage | $73.61 | $31.92 |
| **Total** | **$106.11** | **$75.22** |

The passenger truck pays about three quarters of what the passenger car pays. The passenger car had worse performance and more miles, which accounts for the higher total cost.

**Feedback Loop Example**

For this example, the desired overall decrease in mileage is assumed to be a 5-percent decrease. As total emissions are directly related to mileage, a 5-percent decrease in mileage should correspond to an approximate 5-percent decrease in total emissions. Rather than assume an initial price of zero, we will assume that the base mileage fee of $0.15 per mile is the initial price. A new base fee needs to be determined to attempt to decrease mileage by 5 percent. The assumed elasticity between price and mileage is -0.2. The new required base mileage fee is calculated as:

$$New\ Price\ (P_2) = P_1 \times ({}^{Q_2}/_{Q_1})^{1/\eta} = \$0.15 \times (1 - .05)^{1/-.2} = \$0.1939$$

This new base mileage fee is then applied to performance score, as well as time and location increase factors, to obtain new mileage fees as shown in Table 53.

**Table 53: New Mileage Fees**

| Mileage Type | Fee ($/mile) | |
|---|---|---|
| | **Passenger Car** | **Passenger Truck** |
| Mileage on I-35 and Mopac during Peak Hours | 0.2553 | 0.2180 |
| Peak-Hour Mileage Off Facility | 0.2321 | 0.1982 |
| Mileage on I-35 and Mopac during Off-Peak Hours | 0.1964 | 0.1677 |
| Non-Peak and Off Facility Mileage | 0.1785 | 0.1524 |

The two individual vehicles 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. We also assume that individuals do decrease their mileage by 5 percent in response to the price increase. In that case, the new total charges paid by the two individuals are shown in Table 54.

**Table 54: New Charge Assessed to User**

| Mileage Type | Passenger Car | Passenger Truck |
|---|---|---|
| Mileage on I-35 and Mopac during Peak Hours | $4.94 | $1.15 |
| Peak-Hour Mileage Off Facility | $35.65 | $52.18 |
| Mileage on I-35 and Mopac during Off-Peak Hours | $7.59 | $1.77 |
| Non-Peak and Non-Facility Mileage | $121.25 | $80.12 |
| **Total** | **$169.43** | **$135.22** |

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. Of course, the final charges in this example are fairly high, especially as an approximate monthly payment. The fees could certainly be adjusted so that an undue burden is not placed on any users. Equity for lower-income travelers would be a concern, but is beyond the scope of this project.

## 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 would be used in the same manner. Additionally, the total price the user owes, as calculated in this example, may be higher than desired. However, the actual base rate used could easily be adjusted, and the same methods would be used. Finally, application to heavy-duty vehicles would be quite similar, with the proper data available to calibrate the performance measures. The next chapter gives final conclusions for the whole project.

# CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

The goal of this research was to attempt to use performance measurement to incorporate air quality and energy goals into a mileage-based fee system. While mileage fees are a significant area of research, especially regarding revenue generation and congestion mitigation, this research represents a first step to incorporating other policy goals into such a pricing system. 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 user fee that would help achieve air quality goals. Use of this performance measurement and pricing framework was demonstrated in a small case study. This chapter gives a brief overview of the research process and results.

## General Findings

### *Performance Measurement and Transportation Effects on Air Quality*

Performance measurement is very useful when attempting to relate transportation activities with resulting air quality impacts. Establishing a framework of measures allows multiple factors to be accounted for that may have an effect on vehicle emissions. Tracking changes in performance allows progress toward desired goals to be determined. In other words, improved performance overall should contribute to meeting established air quality goals. In addition, use of both individual-level and system-level measures is desirable. Using system-level measures that present average performance values for a vehicle class allows individual performance to be compared to other similar users. Individuals that perform worse than average should be targeted for the most improvement, and could be monetarily penalized to encourage greater improvement. On the other hand, individuals that perform better than average should not be unduly penalized, although continued improvement is desired.

In this report, performance measures were selected that relate transportation to the emission of air pollutants and consumption of energy. Better performance 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 project are:

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

Selected measures for this project 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; and
9. Driver training.

While Measures 6 and 9 do not directly contribute to decreasing emissions rates, they do relate to the framework goals as they would indirectly reduce overall emissions. 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, 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.

*Relationship between Driving Behavior and Pollutant Emissions*

One step undertaken in this project was to better define the relationship between driver behavior and resulting changes in emissions rates. While emissions were generally expected to increase with 'aggressive driving' behaviors, the exact relationship was not known. Actual driving behavior was analyzed for the above Measures 7 and 8. This analysis was used to establish the threshold acceleration levels used to define 'hard' acceleration and deceleration, which was taken as the $85^{th}$ percentile for different speed categories. Additionally, analysis of several speed profiles was studied and graphed to show the relationship between emissions rates and aggressive driving behavior. The aggressive driving behaviors considered for this project 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.

*Use of Performance Measurement to Meet Air Quality Goals*

For this framework, Measures 3, 4, 5, 7, and 8 were combined to obtain approximate emissions rates for an individual. 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 increase emissions. Similarly, scaling factors were developed to reward users that have vehicles with high EPA Air Pollution Scores or high fuel efficiency. These scaling factors decrease the base emission rate to the standard that vehicle met for several pollutant types. 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. Therefore, 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. 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 emissions rates.

*Linking Mileage-Based User Fees to Performance Measures*

Based on literature, MBUFs have been used for revenue generation, but have also been used to address policy goals such as congestion reduction, recovering maintenance costs, and encouraging mode shifts. Addressing environmental problems such as air pollution 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 project, 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. The exact external cost could be used as a mileage fee, or could be included as a base mileage fee. For this project, a base mileage fee of 15 cents per mile was used, which likely would include the external costs based on calculations in various literature sources. The base fee of 15 cents per mile was determined to be an amount that would be most likely to influence driver behavior, and is used in this report. In this report, a base fee of 30 cents per mile was suggested for heavy-duty vehicles to reflect the fact that heavy-duty vehicles emit more pollutants than light-duty vehicles; however the chosen base fee could be changed for each vehicle class based on relative emission amounts. To determine the actual mileage fee assessed to an individual, the above final performance score and system-level average score are used. 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.

*Performance Framework and Results of Case Study*

The case study undertaken in the last chapter illustrates how the performance measurement and pricing framework could actually be used. The framework was applied to actual travel information for two individuals, although some information had to be assumed. However, performance measures were converted to a final score, and applied to pricing, as desired. 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. As much of the desired heavy-duty vehicle data were not available, the framework could easily be expanded to include better performance measures for heavy-duty vehicles if the data were obtained. 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. Since location of mileage is included, the system could be applied only to certain facilities, such as highways, if desired. In addition, if on-board diagnostic units were more readily available than GPS units, time and location information could be omitted, and simple odometer mileage could be used.

## Recommendations for Future Work

The area of mileage pricing, especially to address desired policy goals, is currently an important area of research. This project 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.

In addition, other research efforts could significantly contribute to the framework developed in this project. 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 were not readily available for this project. Such data provide the opportunity to investigate both vehicle characteristics of heavy-duty vehicles, and the effect of different driving behaviors on emissions. Finally, the case study undertaken for this project 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.

### Concluding Remarks

This research provides a method for addressing air quality goals through pricing of transportation users. 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.

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## APPENDIX A: LIST OF ACRONYMS AND ABBREVIATIONS

AASHTO—American Association of State Highway and Transportation Officials
AC—Air Conditioning
AFV—Alternative Fuel Vehicle
ALVW—Adjusted Loaded Vehicle Weight, average of empty weight and GVWR
AQ—Air Quality
AVI—Automatic Vehicle Identification
CAA—Clean Air Act (1970)
CAFE—Corporate Average Fuel Economy
CBD—Central Business District
CDOT—Colorado Department of Transportation
CFC—Chlorofluorocarbon
CNG—Compressed Natural Gas
CO—Carbon Monoxide
$CO_2$—Carbon Dioxide
$CO_2e$—Carbon Dioxide Equivalent
DelDOT—Delaware Department of Transportation
DOE—Department of Energy
DOT—Department of Transportation
DPM—Diesel Particulate Matter
DSRC—Dedicated Short Range Communications
E85—Blend of 85% denatured ethanol fuel and gasoline
EAC—Early Action Compact
EPA—Environmental Protection Agency
ESAL—Equivalent Single Axle Load
ETR—Express Toll Route
EU—European Union
FIP—Federal Implementation Plan
GHG—Greenhouse Gas
GIS—Geographic Information System
GNSS—Global Navigation Satellite System
GPS—Global Positioning System
GSM—Global System for Mobile Communications (originally Groupe Spécial Mobile)
GVWR—Gross Vehicle Weight Rating, maximum fully loaded vehicle weight
HC—Hydrocarbon
HCHO—Formaldehyde
HGV—Heavy Goods Vehicle
HLDT—Heavy Light-Duty Trucks, a truck between 6001 and 8500 pounds GVWR
HOT—High Occupancy Toll
HOV—High Occupancy Vehicle
HVF—Heavy Vehicle Fee
I—Interstate
IRIS—Integrated Risk Information System
ISTEA—Intermodal Surface Transportation Efficiency Act (1991)
ITS—Intelligent Transportation Systems

**LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)**

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
LED—Light-Emitting Diode
LEV—Low Emission Vehicle
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
mmt$CO_2$e—Million Metric Ton Carbon Dioxide-Equivalent Emissions
MnDOT—Minnesota Department of Transportation
MOVES—MOtor Vehicle Emission Simulator
mph—Miles Per Hour
mph/s—Miles Per Hour Per Second
MPO—Metropolitan Planning Organization
MSAT—Mobile Source Air Toxic
MTBE—Methyl Tert-Butyl Ether
NA—Non-Attainment
NAAQS—National Ambient Air Quality Standards
NCHRP—National Cooperative Highway Research Program
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
OBD—On-Board Diagnostic
OBU—On-Board Unit
ODOT—Oregon Department of Transportation
OTAQ—Office of Transportation and Air Quality (EPA)
PAYD—Pay-As-You-Drive
Pb—Lead
PEMS—Portable Emissions Measurement System
PIARC— Permanent International Association of Road Congresses (World Road Association)
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
POM—Polycyclic Organic Matter
ppb—Parts Per Billion
ppm—Parts Per Million

**LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)**

$R^2$—represents the coefficient of determination
RV—Recreational Vehicle
SAFETEA-LU—Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
SIP—State Implementation Plan
$SO_2$—Sulfur Dioxide
SOV—Single Occupant Vehicle
SOx—Sulfur Oxides
SR—State Route
SUV—Sport Utility Vehicle
TCEQ—Texas Commission on Environmental Quality
TDP—Time-Distance-Place
THC—Total Hydrocarbons
TRANSIMS—TRansportation ANalysis SIMulation System
TRB—Transportation Research Board
TTI—Texas Transportation Institute
TxDOT—Texas Department of Transportation
VM—Vehicle Mileage
VMT—Vehicle Miles Traveled
VOC—Volatile Organic Compound
VSP—Vehicle Specific Power
$\mu g/m^3$—Micrograms Per Cubic Meter

## APPENDIX B: EFFECTS AND OUTCOMES OF COMMON AIR POLLUTANTS



| Effects of Common Air Pollutants from Transportation | | | |
|---|---|---|---|
| **Pollutant** | **General Information** | **Health Effects** | **Environmental Effects** |
| Carbon monoxide (CO)<br>A colorless, odorless gas; also poisonous[1, 2] | • Formed when carbon in fuel is not completely burned—about 56% comes from motor vehicle emissions (may be up to 85-95% in cities) and 22% from non-road engines<br>• Highest levels typically occur in the colder months<br>• Transportation accounts for 70-90% of CO emissions | • Reduces oxygen delivery to organs and tissues in the body<br>• Can cause vision problems, reduce ability to work or learn, reduce manual dexterity, and cause difficulty performing complex tasks. High levels can cause death.<br>• The health threat is more severe for people who suffer from heart disease.<br>• 0.5% in the air can prove fatal in less than 30 minutes by asphyxiation. | • Contributes to formation of smog ground level ozone as a catalyst |
| Ozone ($O_3$)<br>A pale blue gas composed of three oxygen atoms[3, 2] | • “Good ozone” protects earth from the sun. It is formed naturally about 10-30 miles above the surface in the stratosphere through ultraviolet radiation. It is essential—a 5% drop in concentration could cause 10% more skin cancer and eye cataracts.<br>• “Bad ozone” occurs at ground- | • At particular risk are children, the elderly, people with lung disease, and people who are active.<br>• Ozone causes airway irritation, coughing, pain when breathing, congestion, wheezing and difficulty breathing during exercise or outdoor activities, inflammation (like a sunburn | • Interferes with the ability of sensitive plants to produce and store food<br>• Damages the leaves of trees and other plants, which negatively impacts their appearance<br>• Reduces forest growth and crop yield, potentially impacting species diversity in |

[1] http://www.epa.gov/air/urbanair/co/index.html

[2] 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.

[3] http://www.epa.gov/air/ozonepollution/

| Effects of Common Air Pollutants from Transportation | | | |
|---|---|---|---|
| **Pollutant** | **General Information** | **Health Effects** | **Environmental Effects** |
| | level, and is created by a chemical reaction between NOx and VOC in sunlight, especially in the summer and urban areas. It can also be carried hundreds of miles in the wind. | on the skin), aggravation of asthma, bronchitis, and emphysema, increased susceptibility to respiratory illnesses, and permanent lung damage with repeat exposure. | ecosystems<br>• Degrades structures (metal and concrete) through oxidation |
| Lead (Pb)<br>A naturally occurring metal, but extremely poisonous[4, 2] | • Emissions of lead from motor vehicles has declined 95% from 1980 to 1999 due to EPA regulations (levels of lead in the air decreased 94%) | • Blood distributes lead throughout the body; it accumulates in the bones and can affect the oxygen carrying capacity of blood, causing anemia<br>• Can affect the nervous system, metabolism, kidney function, immune system, reproductive and developmental systems, and cardiovascular system, depending on exposure level<br>• May cause behavioral problems, learning deficits, and lower IQ in infants and young children, even at lower levels | • Accumulates in soils and sediments, and can be transported in the atmosphere.<br>• Loss in biodiversity, changes in community composition, decreased growth and reproductive rates in plants and animals, and neurological effects in vertebrates |
| Nitrogen dioxide ($NO_2$)<br>One form of NOx, a brown odorless gas[5, 2] | • Transportation accounts for 45-50% of NOx<br>• Control measures that reduce $NO_2$ typically reduce other types of gaseous NOx<br>• Near roadway measures can be | • Short-term exposure (30 minutes to 24 hours) linked to adverse respiratory effects, including airway inflammation, and eye irritation<br>• People with asthma, children, | • Can prevent the growth of crops and reduce agricultural yields<br>• Are a catalyst for ozone, and a component of smog and acid rain |

[4] http://www.epa.gov/air/lead/
[5] http://www.epa.gov/air/nitrogenoxides/

**Effects of Common Air Pollutants from Transportation**

| Pollutant | General Information | Health Effects | Environmental Effects |
|---|---|---|---|
| | 30-100% higher than concentration away from roadway, and in-vehicle concentration can be 2-3 times higher | and the elderly are particularly susceptible | |
| Particulate matter (PM)<br>A mixture of tiny particles and liquid droplets[6, 2] | • ‘Primary particles’ are directly emitted and ‘secondary particles’ are created by chemical reactions in the atmosphere. They are made up of many things, including acids, organic chemicals, metals, and soil/dust particles.<br>• ‘Inhalable course particles’ are between 2.5 and 10 micrometers in diameter, and ‘fine particles’ are less than 2.5.<br>• Transportation accounts for about 25% of PM | • The smaller the particle, the more dangerous because they can get deeper into your longs, and potentially the bloodstream.<br>• Most susceptible are children, the elderly, and people with heart or lung disease.<br>• PM is linked to increased respiratory symptoms, decreased lung function, aggravated asthma, development of chronic bronchitis, irregular heartbeat, nonfatal heart attacks, and premature death in people with heart or lung disease. Also a carcinogen. | • Visibility reduction—$PM_{2.5}$ is a component of haze<br>• Environmental damage—includes making lakes and streams acidic, changing the nutrient balance in coastal waters and large river basins, depleting nutrients in soil, damaging sensitive forests and farm crops, and affecting diversity of ecosystems. Also, PM can travel long distances carried by the wind.<br>• Aesthetic damage—can stain/damage stone and other materials, which includes objects like statues and monuments |
| Sulfur dioxide ($SO_2$)<br>A heavy colorless gas with a strong odor, one form of SOx[7, 2] | • Transportation accounts for about 5% of emissions, but related industries like petrochemical are high emitters<br>• Control measures that reduce $SO_2$ typically reduce other | • Short-term exposure (5 minutes to 24 hours) linked to adverse respiratory effects like bronchoconstriction and increased asthma symptoms, and eye irritation | • Can inhibit plant physiology, and a component of acid rain<br>• Has a counter effect on greenhouse gases by blocking radiation |

[6] http://www.epa.gov/air/particlepollution/
[7] http://www.epa.gov/air/sulfurdioxide/

**Effects of Common Air Pollutants from Transportation**

| Pollutant | General Information | Health Effects | Environmental Effects |
|---|---|---|---|
| | types of gaseous SOx | • Children, the elderly, and asthmatics are particularly susceptible (asthmatics especially at elevated breathing like when exercising) | |
| Hydrocarbons and volatile organic compounds (HC and VOC)2 | • HC are a group of chemical compounds made of hydrogen and carbon. Called VOCs when in a gaseous form. Typically the result of incomplete gasoline combustion or petrochemical industry byproducts.<br>• Transportation accounts for 40-50%. | • All are somewhat carcinogenic, but heavy HCs are worse than light HCs<br>• Fatal at high concentrations | • Harmful to crops and accumulates in food chain<br>• Catalysts for ozone, and components of smog and acid rain |
| Carbon Dioxide ($CO_2$)<br>A colorless, odorless gas composing 0.04% of atmosphere2 | • It is an important temperature regulator of the atmosphere<br>• It is emitted with burning of fossil fuels. Transportation accounts for about 30% of emissions in developed countries, and 15% worldwide. Within transportation, about 66% is from gasoline combustion, 16% from diesel, and about 15% from jet fuel. | • High concentrations (5000 ppm) may cause breathing disorders | • Essential element of photosynthesis<br>• Large quantities in the atmosphere are assumed to be linked to the greenhouse effect |
| Chlorofluorocarbons (CFCs)<br>Colorless, stable, and non-toxic gases or liquids2 | • Within transportation, the main source is vehicle air-conditioning systems, which account for about 20% of CFC emissions, although they have gotten less in developed | • No noticeable direct effects, but indirectly may increase skin cancer, eye cataracts, and deficiencies of the immune system | • Because of ozone damage, indirectly contributes to crop/plant damage and increased ground level ozone (through photochemical smog) |

| Effects of Common Air Pollutants from Transportation | | | |
|---|---|---|---|
| **Pollutant** | **General Information** | **Health Effects** | **Environmental Effects** |
| | countries with recent legislation<br>• Reduce the concentration of stratospheric ozone, which absorbs harmful ultraviolet rays from the sun; can stay in the atmosphere 70-200 years | | |
| Mobile Source Air Toxics (MSATs) Various compounds[8], [9] | • Some are present in gasoline, and are emitted when gas evaporates or are emitted with unburned fuel<br>• Many have cancerous and other health effects on humans and animals<br>• The EPA has a list of 93, with 8 key MSATs: diesel exhaust, benzene, 1,3-butadiene, acrolein, formaldehyde, acetaldehyde, naphthalene, and polycyclic organic compounds | • Exposure has been linked to adverse health effects such as respiratory problems, birth defects, cardiovascular problems, and childhood cancer<br>• Many are known or suspected carcinogens, and could cause premature death<br>• Risk increases with exposure—living near sources of MSATs can significantly increase risk | • MSATs are also linked to health problems in animals |

[8] Texas Transportation Institute. *The Texas Guide to Accepted Mobile Source Emission Reduction Strategies*. TxDOT Contract 50-7XXIA001, Texas Department of Transportation, August 2007.
[9] 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, August 14, 2008.

**Effects of Air Pollution Outcomes**

| Pollution Outcome | General Information | Health Effects | Environmental Effects |
|---|---|---|---|
| Smog2 | • A mix of solid and liquid fog and smoke particles formed through the accumulation of CO, ozone, HC/VOC, NOx, SOx, water, PM, and other chemical pollutants. Called 'photochemical smog' with higher HC/VOC concentration.<br>• Strongly linked to transportation and industrial activities, especially in urban areas. Particularly dense during thermal inversion. | • Effects are a conjunction of its major components—especially visibility impairment | • Effects are a conjunction of its major components—especially visibility impairment |
| Acid rain/acid decompositions (dry form)2 | • When dissolved in water, sulfuric and nitric acids ($H_2SO_4$ and $HNO_3$) lower the pH. Can be carried long distances in weather systems, and then falls as either acid rain or fog.<br>• Based on the contribution of transportation on concentrations of $SO_2$, NOx, and HC/VOC, it may account for 10-30% of acid rain depending on region. | • May cause respiratory irritation when inhaled as a mist | • Sufficient amounts of acid can damage historical structures<br>• Changes chemical composition of soil—on a large scale can reduce the available biomass (beneficial on a small scale)<br>• Can gradually destroy life in lakes and rivers by changing the pH<br>• Known to alter the ecological balance of continental ecosystems, especially in industrialized areas. |
| Odors<br>Subjective perception of the sense of smell2 | • Major sources within transportation are diesel and gasoline engines, especially prevalent in smog conditions. Mostly an annoyance. | | |

## APPENDIX C: NOTES FROM BRAINSTORMING SESSION, NOVEMBER 24, 2010

Overall Notes:

- The primary objective to keep in mind is the need to bridge performance measures to fees
- The four goals represent what we are trying to achieve in broad terms
- Ultimately—what is the impact on health, environment, etc.?
- We are interested in factors that affect emissions per trip (i.e., speed, # stops, acceleration, etc.) to be applied to a mileage-based fee
- Much of the measure selection or actual use depends on available technology and the ability to pull data from the vehicle

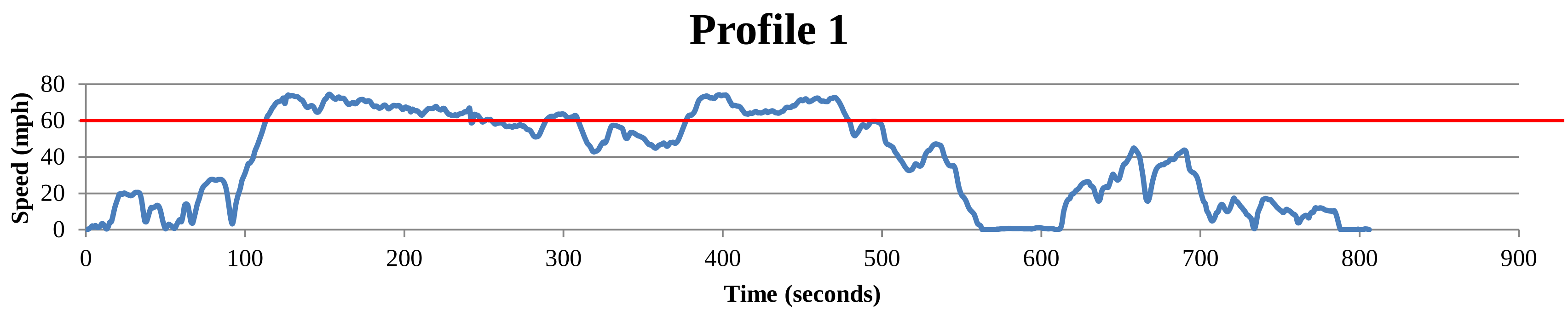
Notes on Objectives:

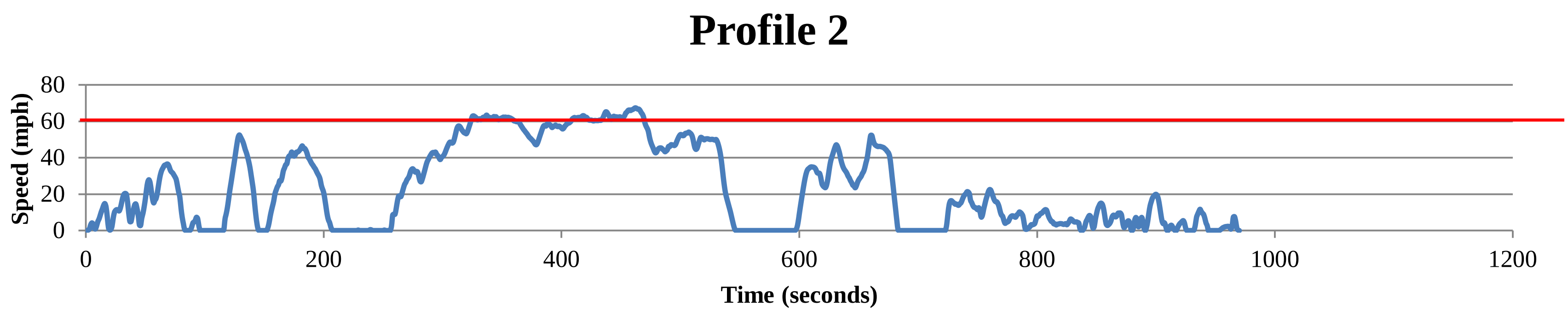
- Rephrase objectives to be clearer to the lay-person, if possible
- Info from Massachusetts Institute of Technology (MIT)—looking at technology options/possibilities
- Objective 1 – change to 'reduce number of miles of travel in a vehicle'
  - A mileage fee targets all vehicles, unlike the fuel tax
- Objectives 3 and 4
  - Clarify difference between low emission vehicles and more fuel efficient vehicles
  - What greenhouse gases are associated with compressed natural gas (CNG) and electric vehicles? There must be some impact somewhere for electric vehicles, although it may be a point source (i.e., power plant)…
    1. Could use something like EPA equivalent of 99 mpg for electric vehicles (check value)
- Objective 5
  - Telecommuting and carpooling fall, at least in part, under Objective 1, in that charging by the mile would encourage such behavior; also data would not be reliable
  - Seattle vanpooling project—related to verifying ridesharing (evolution of technology)
  - Potential information from MIT looking at technology
  - How can pricing be used for mode shift (Miami?)
- Objective 7
  - Would a mode shift to 'better' freight modes be useful, applicable, or measureable (i.e., shifting freight from truck to rail)?
  - Still kind of a grey area for freight in terms of data, due to the private nature of freight travel
- Objective 8
  - Need to have this program before we can have this measure, but for now we will assume that this training would be available
  - Would have to specify the duration of the financial benefit—i.e., would it be a one-time price return, or a reduction of the fee for the year, could it be renewed every year, etc.

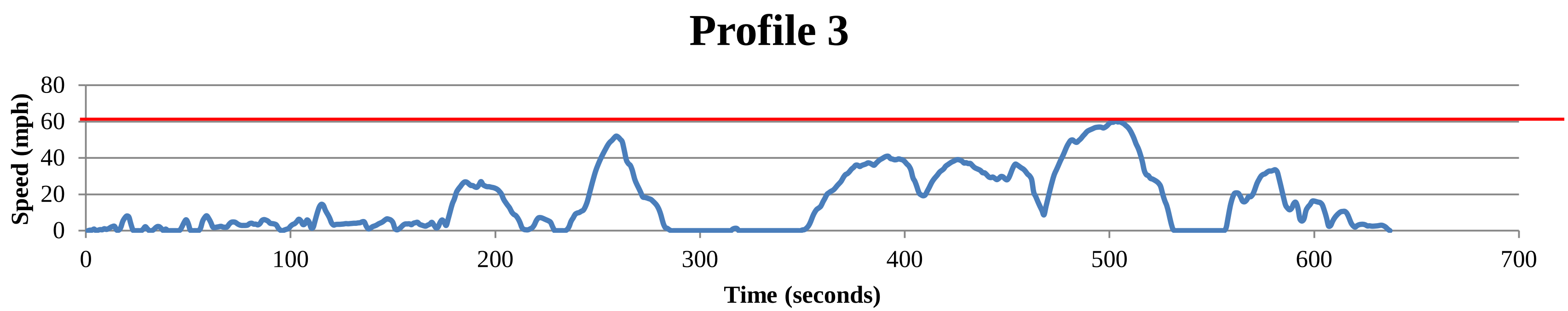
Notes on Measures

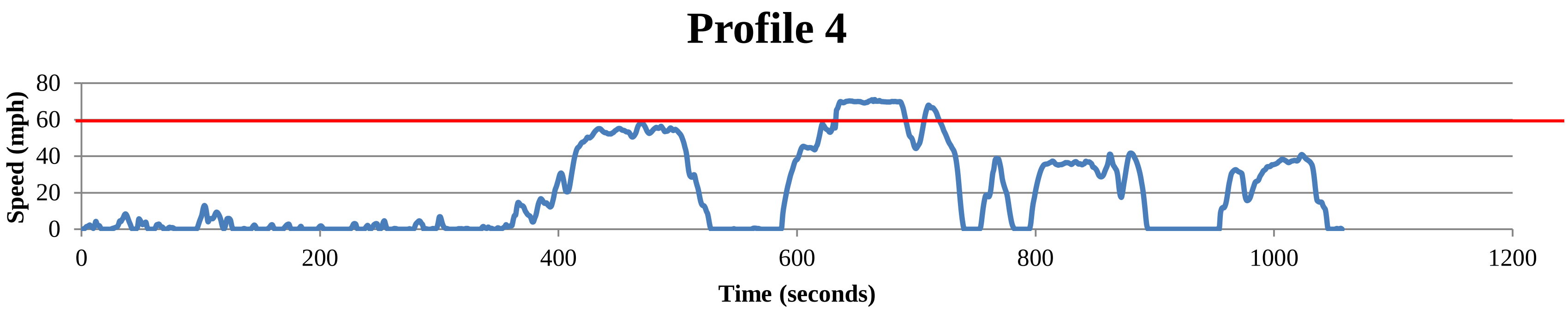
- Objective 1
    - Currently, existing per-year data (TxDOT) is per county, broken into basic facility types
    - If all vehicles were equipped with the necessary technology data would be better, BUT this is maybe 20 years in the future
    - Without technology component, can only currently look at odometer for mileage
    - Also, if only some people have the technology, they may not be representative of all drivers, as they may not have the same incentives
    - What is the potential response of people to the technology divide?
- Objective 2
    - VMT, as in Objective 1, but should be split into desired categories rather than aggregated
- Objectives 3 and 4
    - Some potential measures require actual measurement, while others are set vehicle characteristics
    - Currently there is no system-level measurement of these types of measures, but it would be possible (i.e., fuel economy, emission rating, etc.)
    - What does registration data have?
    - Will come back to these objectives/measures in future
- Objective 5
    - Which would be easier to measure—number of trips or passenger miles?
    - What would be the technology component of this? Potentially some sort of identifier for passengers, like a toll-tag or even some sort of iPhone app?
    - How could ridesharing be tracked?
    - Need to look at more literature for this objective
- Objective 6
    - The technology component is actually possible on the individual side, as in tracking things like aggressive driving, speed, etc.
    - Speed limits, however, would be too detailed and change too often to keep track of easily
    - For now, focus only on the emission reduction (in other words, without thought to safety, etc.)
    - This category would definitely be a hard sell to the public—however, this system of measures is more to start discussion than to be immediately implemented
    - Is time spent idling too much beyond the driver's control? In addition, the effects of lights, congestion, etc. may be covered already to some extent if we look at time of day
    - Top two measures—speed and aggressiveness (i.e., things like acceleration, hard braking)
- Objective 7
    - Is this objective really even practical? What extent of data can we get?
    - New York study—weight (self-reported), vehicle class, and age
- Objective 8
    - Could this be set up as a learning system like defensive driving is, but it is an eco-driving course?
    - Potential for some fee reduction for participation

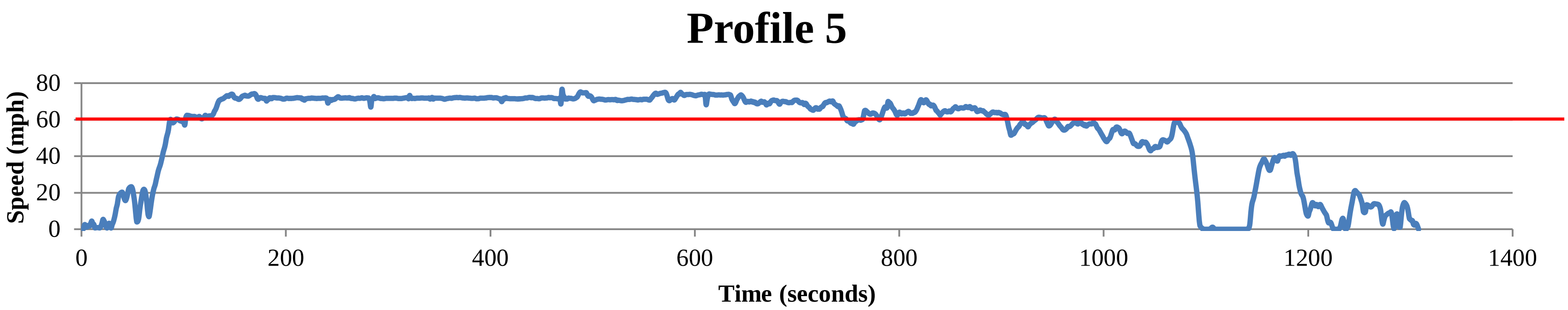
## APPENDIX D: SPEED PROFILES USED TO EVALUATE HIGH SPEED EFFECTS

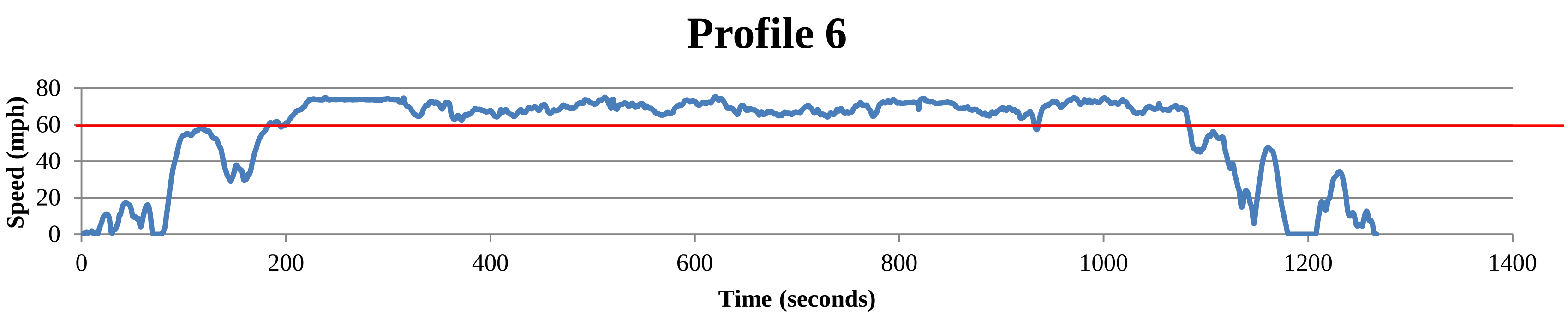


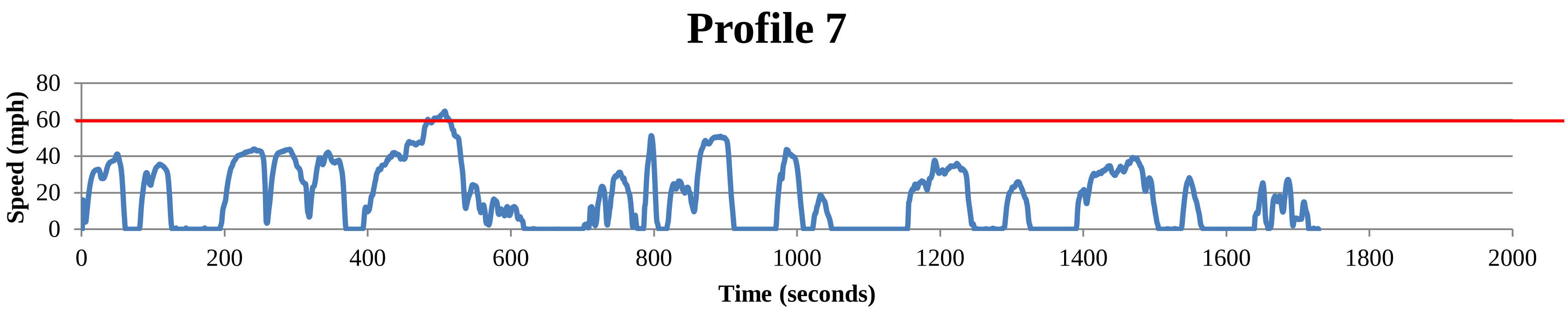



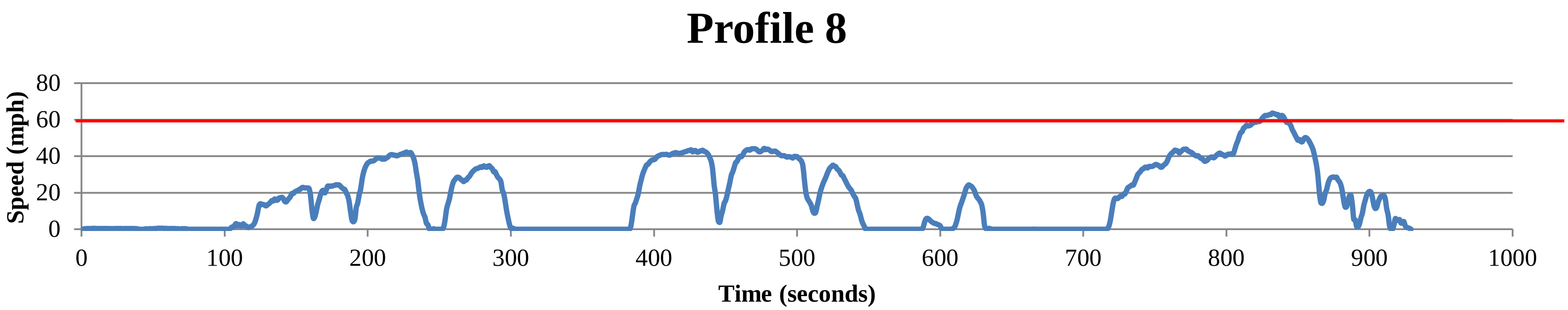



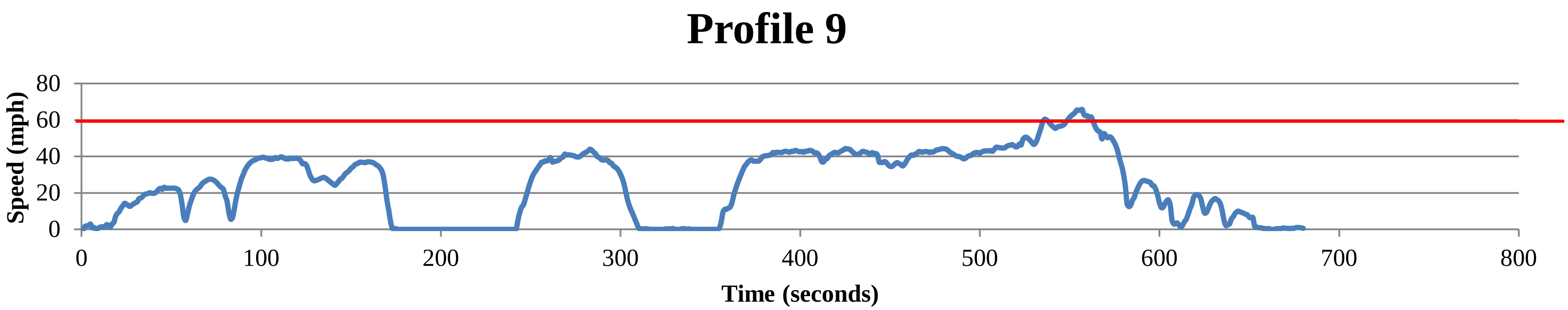

Profile 4
Speed (mph)
80
60
40
20
0
0
200
400
600
800
1000
1200
Time (seconds)


Profile 5
Speed (mph)
80
60
40
20
0
0
200
400
600
800
1000
1200
1400
Time (seconds)

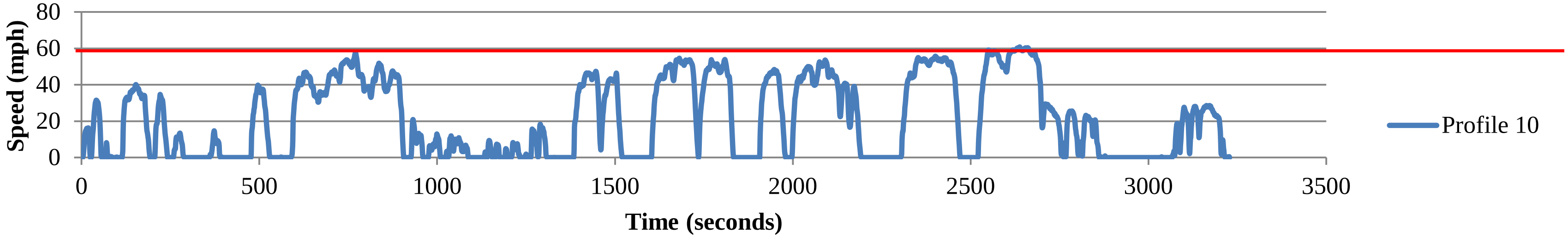

Profile 6
Speed (mph)
80
60
40
20
0
0
200
400
600
800
1000
1200
1400
Time (seconds)


Profile 7
Speed (mph)
0
20
40
60
80
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (seconds)

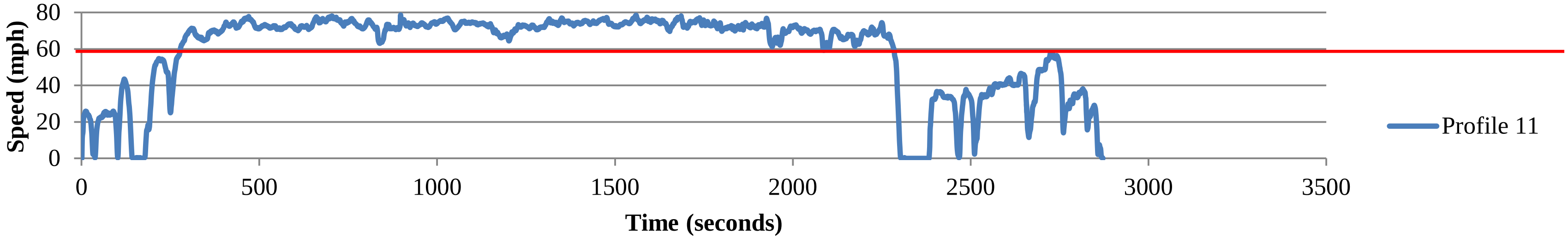

Profile 8
Speed (mph)
0
20
40
60
80
0
100
200
300
400
500
600
700
800
900
1000
Time (seconds)


Profile 9
Speed (mph)
0
20
40
60
80
0
100
200
300
400
500
600
700
800
Time (seconds)

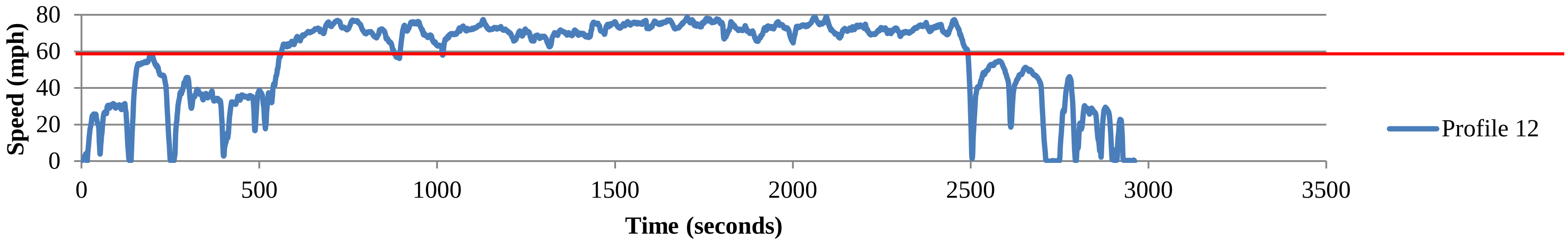
# Profile 10

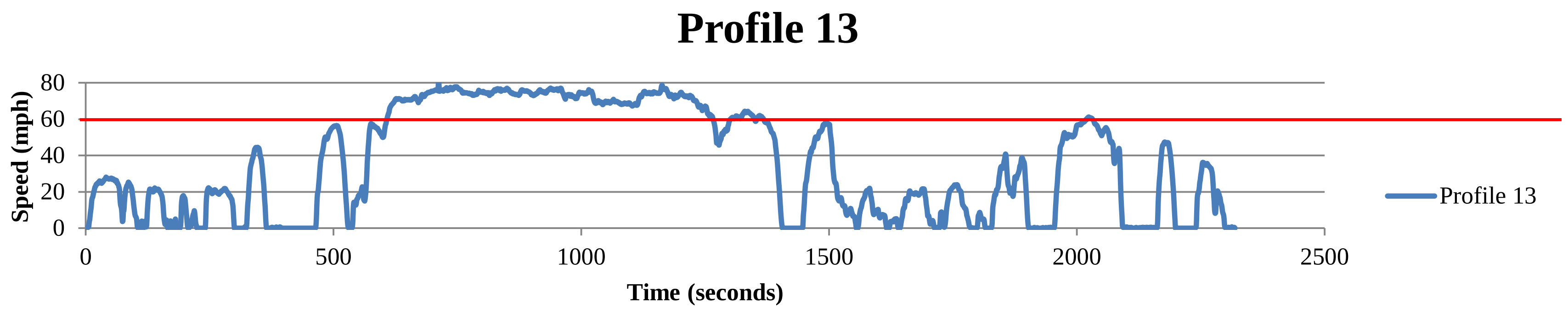



# Profile 11




# Profile 12





Profile 13
Speed (mph)
0
20
40
60
80
0
500
1000
1500
2000
2500
Time (seconds)
Profile 13

## APPENDIX E: NATIONAL EMISSIONS RATES FOR URBAN RESTRICTED AND UNRESTRICTED ACCESS AND 35 AND 60 MPH

**Amount of Pollutant in g/mile for Passenger Cars 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 for Passenger Cars 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 |

**Amount of Pollutant in g/mile for Passenger Trucks 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 for Passenger Trucks 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 |

**Amount of Pollutant in g/mile for Motorcycles 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 for Motorcycles 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 |

| Amount of Pollutant in g/mile for Single Unit Trucks 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+ | 1839.435 | 0.0320 | 0.8774 | 0.3143 | 0.0746 | 0.0229 | 0.0125 | 2774.510 | 0.0746 | 1.4767 | 0.5475 | 0.1738 | 0.0383 | 0.0188 |
| 2007-2009 | 1838.780 | 0.0408 | 3.6749 | 0.4000 | 0.0950 | 0.0279 | 0.0125 | 2773.327 | 0.0949 | 6.1848 | 0.6969 | 0.2212 | 0.0466 | 0.0188 |
| 2004-2006 | 1837.450 | 0.6988 | 7.3499 | 2.8574 | 0.6784 | 0.6573 | 0.0125 | 2770.950 | 1.6273 | 12.3696 | 4.9776 | 1.5798 | 1.1011 | 0.0188 |
| 2000-2003 | 1835.478 | 0.7928 | 12.2093 | 5.2486 | 0.7695 | 0.7097 | 0.0125 | 2767.403 | 1.5776 | 18.1666 | 9.4072 | 1.5312 | 1.1889 | 0.0188 |
| 1996-1999 | 1829.240 | 0.8242 | 18.3155 | 6.0456 | 0.7999 | 0.9037 | 0.0124 | 2756.238 | 1.5610 | 25.6508 | 10.8838 | 1.5150 | 1.3970 | 0.0187 |
| 1992-1995 | 1809.535 | 0.8235 | 20.4776 | 6.0456 | 0.7999 | 1.0613 | 0.0123 | 2720.913 | 1.5597 | 28.8268 | 10.8838 | 1.5150 | 1.5417 | 0.0185 |
| 1988-1991 | 1784.665 | 0.8235 | 24.9305 | 6.0456 | 0.7999 | 1.0012 | 0.0121 | 2676.340 | 1.5597 | 34.9583 | 10.8838 | 1.5150 | 1.5326 | 0.0182 |
| pre-1988 | 1740.056 | 0.8235 | 28.6209 | 6.0456 | 0.7999 | 2.5981 | 0.0118 | 2596.374 | 1.5597 | 40.0739 | 10.8838 | 1.5150 | 3.6672 | 0.0176 |

| Amount of Pollutant in g/mile for Single Unit Trucks 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+ | 1794.785 | 0.0321 | 0.8610 | 0.3179 | 0.0748 | 0.0219 | 0.0122 | 2824.575 | 0.0740 | 1.4949 | 0.5522 | 0.1724 | 0.0392 | 0.0192 |
| 2007-2009 | 1794.133 | 0.0408 | 3.6061 | 0.4046 | 0.0951 | 0.0267 | 0.0122 | 2823.383 | 0.0942 | 6.2609 | 0.7029 | 0.2194 | 0.0476 | 0.0192 |
| 2004-2006 | 1792.827 | 0.7000 | 7.2122 | 2.8899 | 0.6796 | 0.6278 | 0.0122 | 2820.993 | 1.6144 | 12.5217 | 5.0204 | 1.5673 | 1.1258 | 0.0192 |
| 2000-2003 | 1790.883 | 0.8008 | 12.0486 | 5.1465 | 0.7773 | 0.6779 | 0.0122 | 2817.420 | 1.5762 | 18.4152 | 9.5008 | 1.5299 | 1.2156 | 0.0191 |
| 1996-1999 | 1784.740 | 0.8344 | 18.0711 | 5.8988 | 0.8098 | 0.8368 | 0.0121 | 2806.145 | 1.5634 | 26.0465 | 10.9942 | 1.5174 | 1.4335 | 0.0191 |
| 1992-1995 | 1765.315 | 0.8337 | 20.1346 | 5.8987 | 0.8098 | 0.9893 | 0.0120 | 2770.535 | 1.5621 | 29.2803 | 10.9942 | 1.5174 | 1.5799 | 0.0188 |
| 1988-1991 | 1740.790 | 0.8337 | 24.5145 | 5.8987 | 0.8098 | 0.9424 | 0.0118 | 2725.578 | 1.5621 | 35.5250 | 10.9942 | 1.5174 | 1.5736 | 0.0185 |
| pre-1988 | 1696.816 | 0.8337 | 28.1443 | 5.8987 | 0.8098 | 2.5364 | 0.0115 | 2644.950 | 1.5621 | 40.7310 | 10.9942 | 1.5174 | 3.7789 | 0.0180 |

| Amount of Pollutant in g/mile for Buses 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+ | 1219.000 | 0.0326 | 0.5752 | 0.2929 | 0.0760 | 0.0110 | 0.0083 | 2011.590 | 0.0730 | 1.0231 | 0.4888 | 0.1700 | 0.0185 | 0.0137 |
| 2007-2009 | 1218.503 | 0.0429 | 2.6182 | 0.3858 | 0.1000 | 0.0135 | 0.0083 | 2010.607 | 0.0961 | 4.6479 | 0.6437 | 0.2239 | 0.0227 | 0.0136 |
| 2004-2006 | 1217.510 | 0.8056 | 5.2363 | 3.0153 | 0.7818 | 0.3590 | 0.0083 | 2008.610 | 1.8031 | 9.2958 | 5.0312 | 1.7498 | 0.6035 | 0.0136 |
| 2000-2003 | 1216.018 | 1.0273 | 6.3244 | 3.5123 | 0.9964 | 0.3892 | 0.0083 | 2005.623 | 2.1771 | 10.6943 | 6.2393 | 2.1117 | 0.6546 | 0.0136 |
| 1996-1999 | 1211.318 | 1.1654 | 10.6392 | 3.8644 | 1.1301 | 0.6109 | 0.0082 | 1996.233 | 2.4367 | 18.2185 | 6.9857 | 2.3629 | 1.1804 | 0.0136 |
| 1992-1995 | 1196.468 | 1.3624 | 12.3796 | 4.4911 | 1.3214 | 0.6990 | 0.0081 | 1966.548 | 2.8504 | 21.4972 | 8.1220 | 2.7647 | 1.3667 | 0.0134 |
| 1988-1991 | 1177.723 | 1.0702 | 15.0854 | 3.7419 | 1.0386 | 0.7946 | 0.0080 | 1929.073 | 2.2244 | 26.0411 | 6.7399 | 2.1588 | 1.2563 | 0.0131 |
| pre-1988 | 1144.100 | 1.0424 | 17.3245 | 3.8501 | 1.0117 | 1.3787 | 0.0078 | 1861.859 | 2.1524 | 29.8397 | 6.9099 | 2.0891 | 1.8054 | 0.0126 |

| Amount of Pollutant in g/mile for Buses 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+ | 1067.780 | 0.0327 | 0.5239 | 0.2925 | 0.0762 | 0.0100 | 0.0072 | 1985.795 | 0.0723 | 1.0072 | 0.4879 | 0.1685 | 0.0182 | 0.0135 |
| 2007-2009 | 1067.323 | 0.0431 | 2.3852 | 0.3852 | 0.1003 | 0.0123 | 0.0072 | 1984.807 | 0.0952 | 4.5757 | 0.6424 | 0.2218 | 0.0223 | 0.0135 |
| 2004-2006 | 1066.397 | 0.8080 | 4.7703 | 3.0107 | 0.7841 | 0.3282 | 0.0072 | 1982.837 | 1.7867 | 9.1515 | 5.0215 | 1.7339 | 0.5946 | 0.0135 |
| 2000-2003 | 1065.018 | 1.0232 | 5.5432 | 3.3736 | 0.9925 | 0.3569 | 0.0072 | 1979.875 | 2.1660 | 10.5063 | 6.1784 | 2.1009 | 0.6448 | 0.0134 |
| 1996-1999 | 1060.660 | 1.1587 | 9.2725 | 3.6716 | 1.1236 | 0.5314 | 0.0072 | 1970.570 | 2.4269 | 17.9885 | 6.9035 | 2.3534 | 1.1508 | 0.0134 |
| 1992-1995 | 1046.893 | 1.3545 | 10.7054 | 4.2683 | 1.3137 | 0.5884 | 0.0071 | 1941.130 | 2.8390 | 21.2355 | 8.0267 | 2.7536 | 1.3269 | 0.0132 |
| 1988-1991 | 1029.513 | 1.0646 | 13.0409 | 3.5460 | 1.0332 | 0.6841 | 0.0070 | 1903.988 | 2.2153 | 25.7389 | 6.6585 | 2.1500 | 1.2300 | 0.0129 |
| pre-1988 | 998.337 | 1.0375 | 14.9746 | 3.6392 | 1.0070 | 1.2507 | 0.0068 | 1837.349 | 2.1435 | 29.4996 | 6.8244 | 2.0804 | 1.7882 | 0.0125 |

| Amount of Pollutant in g/mile for Combination Trucks 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+ | 2171.280 | 0.0320 | 0.9890 | 0.3211 | 0.0745 | 0.0239 | 0.0147 | 3131.125 | 0.0761 | 1.5761 | 0.5607 | 0.1774 | 0.0387 | 0.0213 |
| 2007-2009 | 2170.533 | 0.0411 | 4.2445 | 0.4129 | 0.0958 | 0.0291 | 0.0147 | 3129.853 | 0.0979 | 6.7596 | 0.7211 | 0.2281 | 0.0471 | 0.0212 |
| 2004-2006 | 2169.050 | 0.7255 | 8.4890 | 3.0354 | 0.7042 | 0.7007 | 0.0147 | 3127.327 | 1.7277 | 13.5192 | 5.3011 | 1.6769 | 1.1430 | 0.0212 |
| 2000-2003 | 2166.833 | 0.8811 | 13.9101 | 5.4962 | 0.8549 | 0.7753 | 0.0147 | 3123.525 | 1.7788 | 19.6279 | 9.8369 | 1.7259 | 1.2614 | 0.0212 |
| 1996-1999 | 2159.843 | 0.9578 | 21.5232 | 6.3474 | 0.9291 | 1.0810 | 0.0147 | 3111.543 | 1.8537 | 28.5207 | 11.4276 | 1.7982 | 1.7440 | 0.0211 |
| 1992-1995 | 2137.745 | 1.0236 | 24.3739 | 6.4733 | 0.9934 | 1.2741 | 0.0145 | 3073.720 | 2.0054 | 32.4408 | 11.7054 | 1.9463 | 1.9927 | 0.0209 |
| 1988-1991 | 2109.858 | 0.9497 | 29.6769 | 6.1733 | 0.9219 | 1.2182 | 0.0143 | 3025.973 | 1.8478 | 39.3163 | 11.1345 | 1.7937 | 1.9140 | 0.0205 |
| pre-1988 | 2059.826 | 0.9849 | 34.0713 | 5.9310 | 0.9559 | 2.5251 | 0.0140 | 2940.327 | 1.9526 | 45.0590 | 10.7758 | 1.8952 | 3.5756 | 0.0200 |

| Amount of Pollutant in g/mile for Combination Trucks 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+ | 2164.950 | 0.0320 | 0.9880 | 0.3256 | 0.0746 | 0.0235 | 0.0147 | 3214.185 | 0.0757 | 1.6072 | 0.5667 | 0.1763 | 0.0398 | 0.0218 |
| 2007-2009 | 2164.200 | 0.0412 | 4.2403 | 0.4188 | 0.0960 | 0.0286 | 0.0147 | 3212.890 | 0.0973 | 6.8927 | 0.7288 | 0.2268 | 0.0485 | 0.0218 |
| 2004-2006 | 2162.717 | 0.7270 | 8.4805 | 3.0788 | 0.7057 | 0.6898 | 0.0147 | 3210.317 | 1.7175 | 13.7853 | 5.3580 | 1.6671 | 1.1768 | 0.0218 |
| 2000-2003 | 2160.495 | 0.8910 | 13.9740 | 5.4637 | 0.8644 | 0.7628 | 0.0147 | 3206.460 | 1.7823 | 20.0761 | 10.0026 | 1.7292 | 1.2991 | 0.0218 |
| 1996-1999 | 2153.510 | 0.9703 | 21.6539 | 6.2895 | 0.9413 | 1.0467 | 0.0146 | 3194.335 | 1.8622 | 29.2049 | 11.6313 | 1.8065 | 1.8033 | 0.0217 |
| 1992-1995 | 2131.403 | 1.0360 | 24.4763 | 6.4149 | 1.0054 | 1.2378 | 0.0145 | 3155.955 | 2.0150 | 33.2287 | 11.9144 | 1.9556 | 2.0574 | 0.0214 |
| 1988-1991 | 2103.505 | 0.9617 | 29.8043 | 6.1173 | 0.9336 | 1.1884 | 0.0143 | 3107.545 | 1.8564 | 40.2865 | 11.3332 | 1.8021 | 1.9791 | 0.0211 |
| pre-1988 | 2053.467 | 0.9958 | 34.2186 | 5.8782 | 0.9665 | 2.5101 | 0.0139 | 3020.677 | 1.9624 | 46.1775 | 10.9686 | 1.9047 | 3.7021 | 0.0205 |

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