DRIVING SEGMENTS ANALYSIS FOR ENERGY AND ENVIRONMENTAL IMPACTS OF WORSENING TRAFFIC

by

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Submitted to the Engineering Systems Division
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ABSTRACT

During the last two decades, traffic congestion in the U.S. has increased from 30% to 67% of peak period travel. Further, current research shows that measures taken within transportation systems, such as adding capacity, improving operations and managing demand, are not enough to keep congestion from growing worse. With the worsening traffic, the vehicle's fuel consumption and pollutant emissions will inevitably increase. As such, this thesis aims to quantitatively evaluate the energy and environmental impacts of worsening traffic on individual vehicles and the U.S. light-duty vehicle fleet, as well as to design feasible measures beyond transportation systems to offset theses impacts.

The fuel consumption and emissions of different vehicle types under different driving situations provide the basis for analyzing the energy and environmental impacts of worsening traffic. This thesis defines the concept of "driving segments" to represent all possible driving situations which consist of vehicle speed, operation patterns and road types. For each vehicle type, its fuel consumption and emissions in different "driving segments" can be developed into a matrix by ADVISOR 2004, the vehicle simulation tool.

Combining the "driving segments" vehicle performance matrices with the model for traffic congestion, the energy and environmental impacts of worsening traffic on individual vehicles can be examined. Based on these impacts, this thesis compares the performance of different vehicle types for both today's and tomorrow's traffic situations. Meanwhile, the on-road fuel economy of each vehicle type has also been calculated to update EPA's fuel economy rating by taking worsening traffic into consideration.

Combining the "driving segments" vehicle performance matrices with a set of models for fleet population, vehicle technology, driving behavior and traffic congestion, the energy and environmental impacts of worsening traffic on the U.S. light-duty vehicle fleet can also be examined. Through sensitivity analysis, this thesis investigates the effects of altering vehicle choice, developing vehicle technology and changing driving behavior on offsetting the fuel consumption and emissions of the U.S. light-duty vehicle fleet caused by worsening traffic through 2030. It is concluded that promoting the market share of advanced vehicle technologies (Hybrids mainly) is the most effective and most feasible method.

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CHAPTER 1: INTRODUCTION

1.1 Motivation

The invention of the petroleum-fueled motor vehicle at the end of 19th century was the prologue for the "golden age" of mobility by improving accessibility, and driving economic development. But in less than one hundred years, the world has also suffered a variety of negative impacts associated with motor mobility, such as traffic congestion, energy shortages, environmental pollution, car accident, etc. In light of the general rules of sustainability, more and more researchers are trying to identify ways to mitigate these negative impacts, while enhancing the positive impacts of mobility in order to achieve "sustainable mobility" (see Figure 1-1), which means the ability to meet the needs of society to move freely, gain access, communicate, trade, and establish relationships without sacrificing other essential human or ecological values today or in the future [WBCSD, 2001].

However, current research on sustainable mobility tends to study traffic congestion, energy consumption and environmental pollution separately and the relationship between these impacts on mobility is often overlooked (see Figure 1-1). Vehicle fuel consumption and emissions are determined by both vehicle technologies and real-world driving situations, such as driving behavior and traffic congestion (see Figure 1-2). When traffic congestion becomes worse, vehicle driving situations will change from "free flow" to "speed up/slow down" and even to "stop-and-go", and such changes will cause more fuel to be wasted through non-productive engine operation [TTI, 2005] and more emissions [Dodder, 2006]. In other words, worsening traffic will acerbate energy consumption and environmental pollution through changing the driving situations for all motor vehicles.

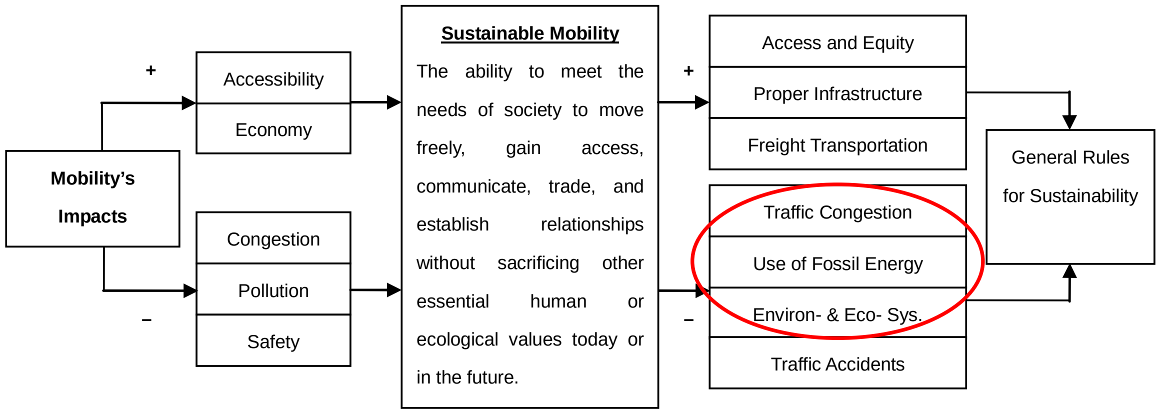

Figure 1-1: Definition for Sustainable Mobility [Adapted from WBCSD, 2001]

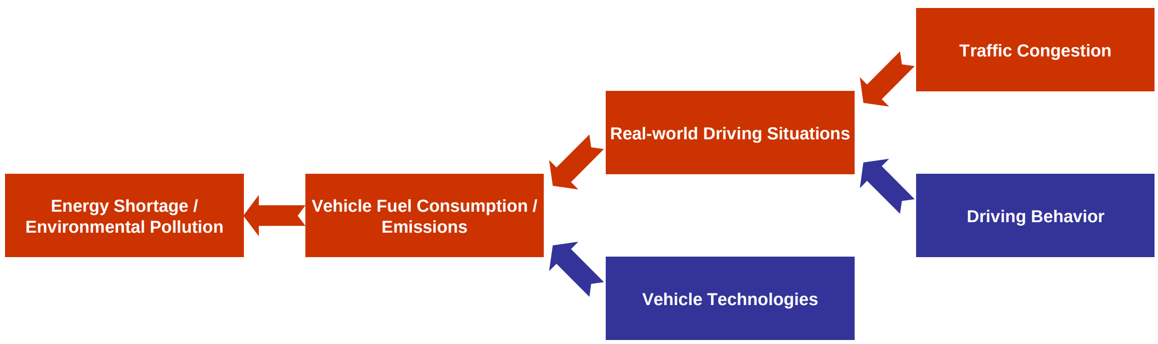

Figure 1-2: Relationship between Traffic Congestion and Energy Consumption / Environmental Pollution

Based on the above qualitative analysis, it would be a pressing task for us to quantify the energy and environmental impacts of worsening traffic, i.e., the increase of vehicle fuel consumption and emissions when traffic congestion becomes worse. There are three major reasons why this task is so important:

First of all, quantifying the energy and environmental impacts of worsening traffic can help us fully understand the relationship between traffic congestion, energy consumption and environmental pollution. The additional fuel consumption and emissions caused by worsening traffic in the past can be identified. And if traffic congestion becomes continuously worse in the future, its impacts on energy and the environment can also be projected and taken as a reference for policy makers.

Second, quantifying the energy and environmental impacts of worsening traffic can help us design feasible measures beyond transportation systems to "offset" these impacts. On one hand, existing research shows that measures taken within transportation systems such as adding road capacity, improving operations and managing demand are not enough to keep congestion from growing worse in many countries and areas [TTI, 2005], and therefore it's necessary to find the measures outside of transportation systems to mitigate the energy and environmental impacts of worsening traffic. On the other hand, qualitative analysis indicates that vehicle fuel consumption and emissions are influenced by not only traffic congestion but also vehicle technologies and driving behavior (see Figure 1-2), and thus it's also reasonable to offset the increase of fuel consumption and emissions caused by worsening traffic through some measures beyond transportation systems, such as altering vehicle choices, developing vehicle technologies or changing driving behavior.

Last but not least, quantifying the energy and environmental impacts of worsening traffic can help us better calculate the "on-road" fuel economy to compare the real performance of different vehicle technologies for both today's and tomorrow's traffic situations. Since the 1970s, the fuel consumption and emissions of motor vehicles have been always tested under standard "driving cycles" (series of data points representing the speed of a vehicle versus time) [ISO, 2003], which unfortunately no longer represent the real-world driving situations [Samuel et al., 2003]. However, once the energy and environmental impacts of worsening traffic are quantified, the limitations of standard driving cycles can be overcome and it will be straightforward to quantify the performance of different vehicle types under any traffic situation.

All in all, quantifying the energy and environmental impacts of worsening traffic is a very necessary and important task for sustainable mobility research. Accomplishing this task is exactly the motivation of this thesis.

1.2 Scope

In order to make a reasonable simplification for the above task while still developing a general framework to quantify the energy and environmental impacts of worsening traffic, this thesis limits its scope on the following two aspects:

First, the U.S. road transportation system from 1982 to 2030 defines the space and time domains to model worsening traffic. During the last two decades, the worst congestion levels (including "Severe" and "Extreme") in the U.S. have increased from 12% to 40% and free-flowing travel in 2003 is less than half of the amount in 1982 (see Figure 1-3), and this trend is forecasted to continue in the future 25 years [TTI, 2005]. Moreover, almost one third of the world's total motor vehicles is in the U.S. and so will be influenced by changing traffic situations [Ward's Communications, 2004]. Therefore the U.S. road transportation system provides a meaningful backdrop to describe how the traffic congestion became worse in the past, as well as how it might worse in the future.

Second, the U.S. light-duty vehicles and their fleet are taken as the object to study the energy and environmental impacts of worsening traffic. In fact, nearly 96% of the U.S. motor vehicles are light-duty vehicles (passenger cars and light trucks with gross weight under 10,000 pounds) [ORNL, 2005], and these light-duty vehicles account for 80% of the U.S. road transportation fuel consumption (equivalent to 39% of the U.S. total petroleum consumption or 16% of the U.S. total energy consumption) and 22% of the U.S. total CO_2 emissions [Bassene, 2001; EIA, 2005]. Therefore, by looking at the light-duty vehicle fleet we capture a majority of road vehicle transportation, and a sizable fraction of national energy consumption and emissions.

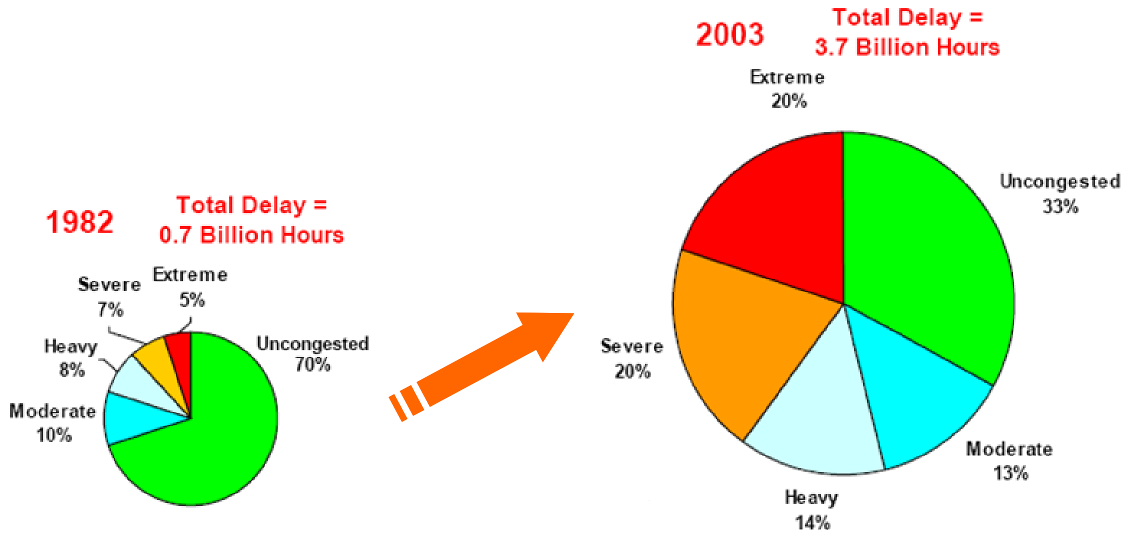

Figure 1-3: The Change of Traffic Congestion in the U.S. [TTI, 2005]

1.3 Objectives

Considering both motivation and scope of this thesis as described above, the objectives of this thesis include:

1) Developing a general framework or methodology to quantify the energy and environmental impacts of worsening traffic;

2) Identifying the additional fuel consumption and emissions of passenger cars and light trucks as well as the U.S. light-duty vehicle fleet caused by worsening traffic in the last two decades;

3) Estimating the energy and environmental impacts of future traffic congestion on the U.S. light-duty vehicle fleet and designing feasible measures beyond transportation systems to offset these impacts;

4) Calculating the on-road fuel economy of light-duty vehicles to improve EPA's outdated fuel economy rating and to compare the real performance of different vehicle types for both today's and tomorrow's traffic congestion levels;

5) Suggesting policy alternatives to improve the energy and environmental performance of light-duty vehicles under different traffic situations.

1.4 Methodology

As illustrated in Figure 1-2, the energy and environmental impacts of worsening traffic can be quantified if worsening traffic can be modeled and combined with vehicle fuel consumption and emissions estimates under a wide variety of driving situations. However, the greatest challenge for this thesis lies in the following three areas involving instantaneous vehicle characteristics (fuel consumption and emissions) under different driving situations:

- Lack of experimental data for instantaneous vehicle characteristics;
- Huge amount of possible driving situations;
- How to describe different driving situations.

Vehicle simulation tools, such as ADVISOR 2004, can simulate the instantaneous vehicle characteristics with appropriate models to overcome the lack of experimental data. The huge amount of driving situations can also be managed by velocity-acceleration (V-A) matrices, which categorize all the reasonable driving situations into a finite number of V-A grids. However, there doesn't exist any easy method for the researchers to describe driving situations effectively and efficiently, especially linking them with both vehicle performance and traffic congestions (see Figure 1-2). In order to meet this challenge, this thesis defines the concept of “driving segments” to characterize all the possible driving situations as the combination of vehicle speed, operation patterns (Free Flow, Speed Up/Slow Down, Stop-and-Go) and road types (Highway, Suburban (Arterial Road), Urban (Side Street)) (see Figure 1-4). Through vehicle speed and operation patterns, “driving segments” can be connected with vehicle performance. Meanwhile, “driving segments” can also be connected with traffic congestion through operation patterns and road types.

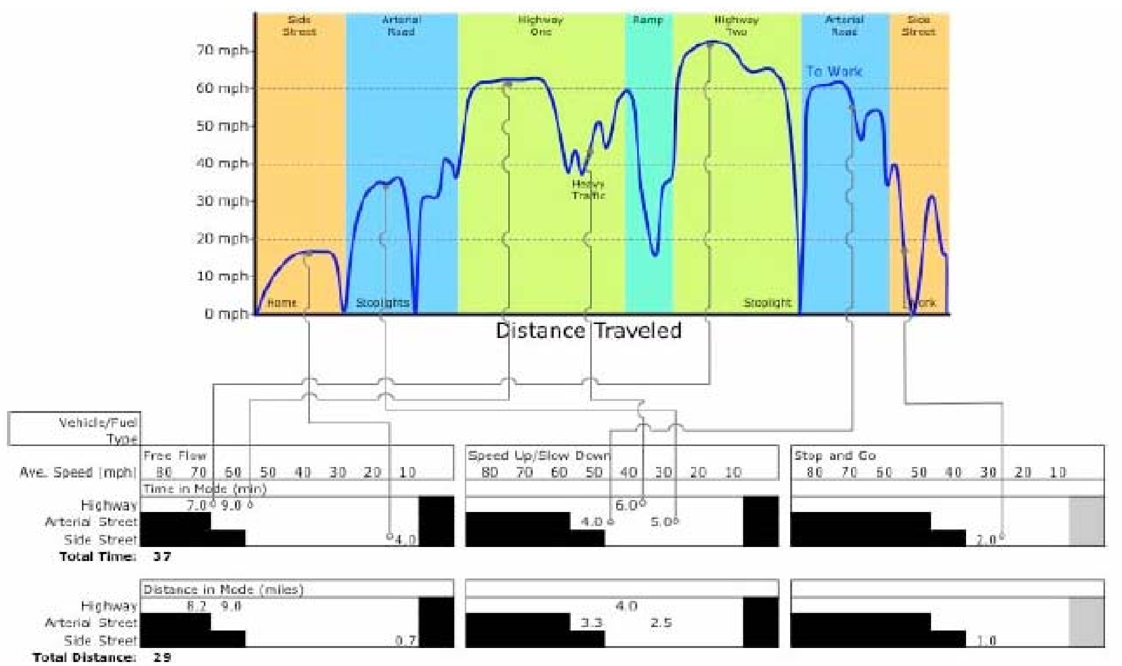

Figure 1-4: Conceptual “Driving Segments” [Connors and Feng, 2005]

From vehicle simulation tools and V-A matrices, the performance of different vehicles under “driving segments” can be developed (see Figure 1-5). And then, integrating these “driving segments” vehicle performance matrices with appropriate model for worsening traffic, this thesis is able to look at the energy and environmental impacts of worsening traffic both qualitatively and quantitatively.

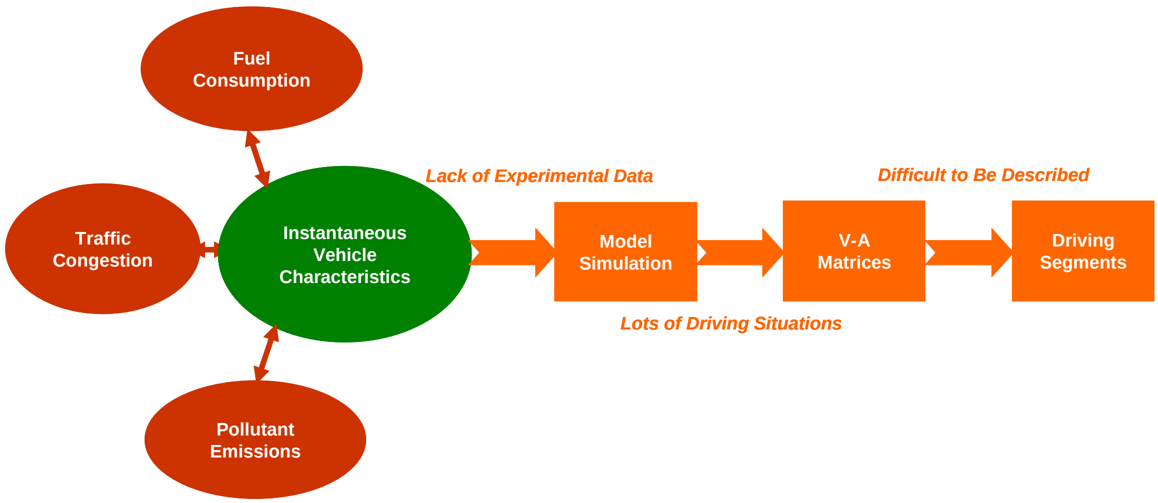

Figure 1-5: "Driving Segments" Methodology

1.5 Thesis Overview

Chapter 2 defines the concept of "driving segments" in detail and then uses ADVISOR 2004 to develop all the "driving segments" vehicle performance matrices for 13 types of passenger cars and light trucks.

Chapter 3 studies the energy and environmental impacts of worsening traffic on individual vehicles. Based on that, the performance of different vehicle technologies are compared for today's and tomorrow's traffic situations, and the on-road fuel economy reflecting the real driving situations are calculated to improve EPA's outmoded fuel economy rating.

Chapter 4 studies the energy and environmental impacts of worsening traffic on the U.S. light-duty vehicle fleet. Meanwhile, the impacts of fleet population, vehicle technology and driving behavior on the fleet fuel consumption and emissions are also quantified as well as compared. Based on that, the feasibility and effectiveness of different measures such as altering vehicle choice, developing vehicle technologies and changing driving behavior to offset the impacts of worsening traffic are investigated.

Conclusions from this thesis are summarized in Chapter 5.

CHAPTER 2: DRIVING SEGMENTS ANALYSIS

2.1 Introduction

Driving situations in the real world are the key to quantify the energy and environmental impacts of worsening traffic by bridging the gap between vehicle performance and traffic congestion (see Figure 1-2). If the vehicle fuel consumption and emissions under any driving situations are known and if the changes of driving situations with worsening traffic can be modeled, the increase of vehicle fuel consumption and emissions can be calculated when traffic congestion gets worse. At short time intervals, driving situations can be described as the instantaneous velocity and acceleration of vehicles. However to model the entire fleet, for long time horizons at this resolution is not feasible.

As such, this Chapter develops the concept of “driving segments” to represent the real driving situations in a simplified but systematic way. The matrices for vehicle fuel consumption and emissions belonging to these “driving segments” are further generated with ADVISOR 2004, the well-known vehicle simulation tool. Based on the “Driving Segments” vehicle performance matrices, the energy and environmental impacts of worsening traffic on individual vehicles as well as on the U.S. light-duty vehicle fleet is investigated in the next two chapters.

2.2 Definition of Driving Segments

As discussed in Chapter 1, in order to describe driving situations effectively and efficiently by linking them with both vehicle performance and traffic congestion, this thesis defines the concept of “driving segments” to characterize all the possible driving situations as the combination of vehicle speed, operation patterns (Free Flow, Speed Up/ Slow Down, Stop-and-Go) and road types (Highway, Suburban, Urban). However, driving situations are normally defined by both the velocity (mph) and the acceleration (m/s^2) of vehicle, which means each point in the velocity-acceleration (V-A) graph represents one specific driving situation. Then, how to connect the definitions for driving situations and “driving segments” together?

First of all, this thesis restricts reasonable driving situations in the area of [V: 0 ~ 80 mph, A: -3.5 ~ 3.5 m/s^2] and then evenly divides this area into 224 grids (16×14, see Figure 2-1) with the consideration of differentiability. For each grid, the corresponding vehicle performance will be measured by the average fuel consumption and emissions of all the driving situations in that grid.

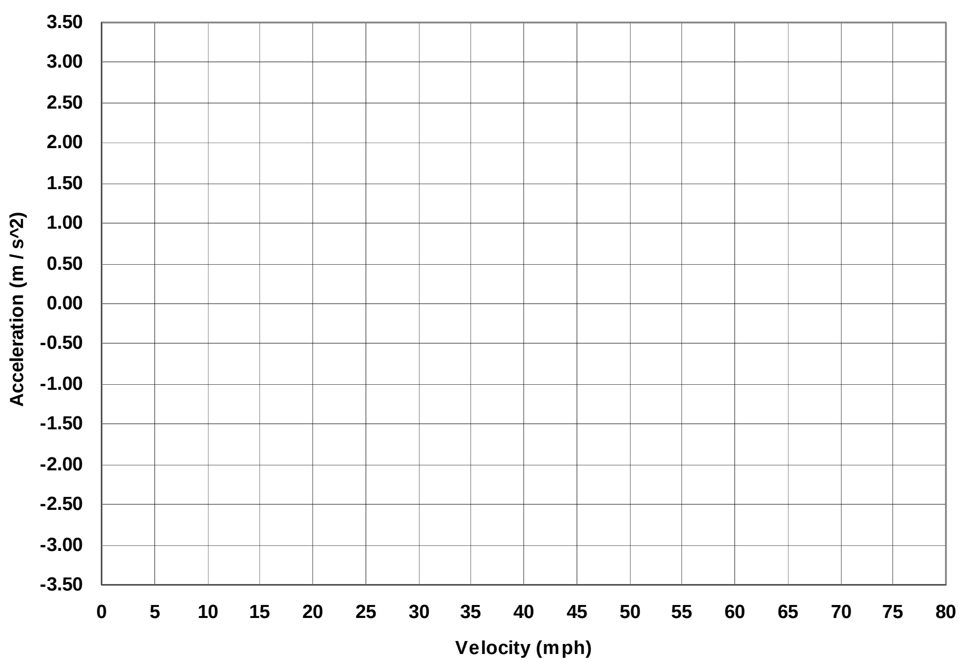

Figure 2-1: Velocity-Acceleration (V-A) Graph

Secondly, in land transportation systems, the concept of "Level-of-Service" (LOS) divides the levels of traffic congestion into six grades (A~F, from the best to the worst) and then defines these grades with road types and vehicle speed [TRB, 2000]. Considering the similarity between operation patterns and traffic congestion, this thesis assumes that "Free Flow" is equivalent to "A~B" levels of traffic congestion, "Speed Up/Slow Down" is equivalent to "C-D" levels of traffic congestion, and "Stop-and-Go" is equivalent to "E~F" levels of traffic congestion. Further, according to existing research [EPA, 1997], this thesis also makes several reasonable assumptions for the range of vehicle acceleration in each level of traffic congestion. All these assumptions and the concept of LOS are summarized in Table 2-1.

Table 2-1: LOS and Basic Assumptions

Road Type	Level-of-Service	Operation Pattern	Velocity (mph)	Acceleration (m/s^2)
Highway	A~B	Free Flow	50~70	-1.0~1.0
	C~D	Speed Up/Slow Down	40~50	-1.5~1.5
	E~F	Stop-and-Go	0~40	-3.0~3.0
Suburban	A~B	Free Flow	30~45	-2.0~2.0
	C~D	Speed Up/Slow Down	15~30	-2.5~2.5
	E~F	Stop-and-Go	0~15	-2.5~2.5
Urban	A~B	Free Flow	20~35	-1.5~1.5
	C~D	Speed Up/Slow Down	10~20	-1.5~1.5
	E~F	Stop-and-Go	0~10	-1.5~1.5

Finally, Table 2-1 reveals the relationships between road types, operation patterns, vehicle velocity and acceleration. Through mapping these relationships into the V-A graph (see Figures 2-2 ~ 2-4), this thesis can connect the definition for driving situations with the definition for "driving segments".

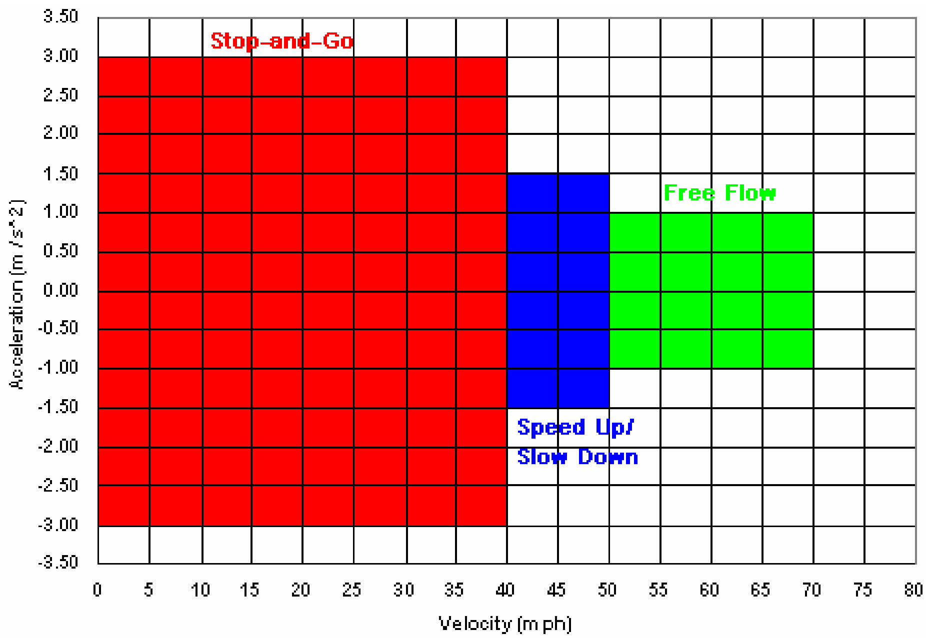

Figure 2-2: Driving Situations and "Driving Segments" (Highway)

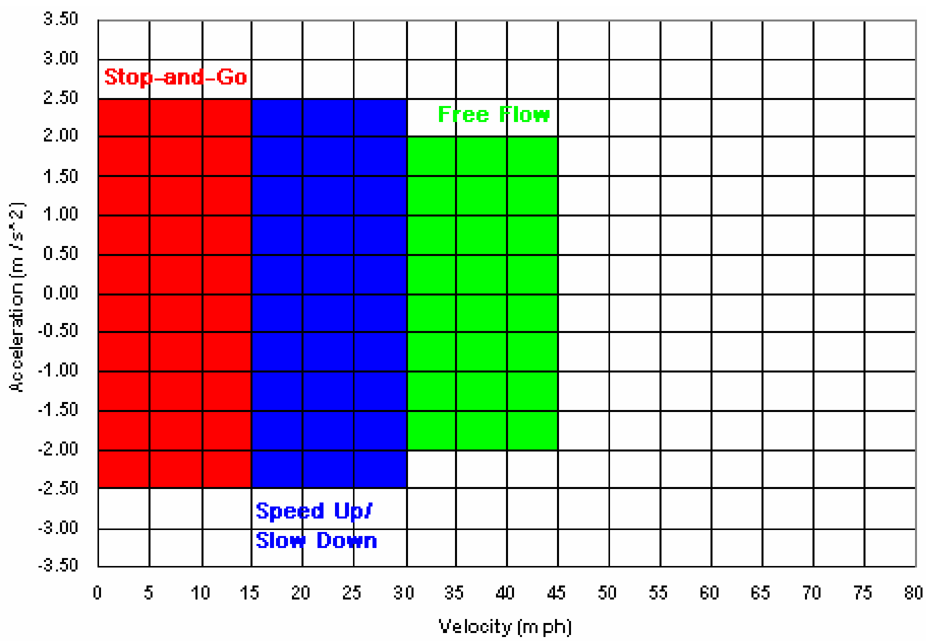

Figure 2-3: Driving Situations and "Driving Segments" (Suburban Road)

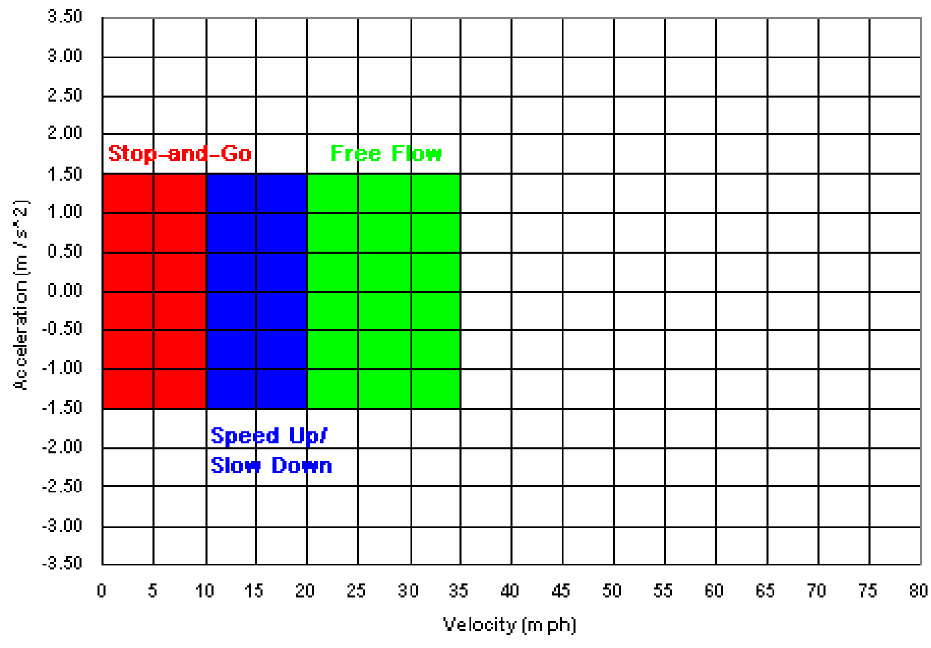

Figure 2-4: Driving Situations and "Driving Segments" (Urban Street)

For example, Figure 2-5 shows three sample "driving segments" in the V-A graph (vehicle speed is taken as the average velocity instead of the velocity range to be more specific): DS-1 represents the segment of [vehicle speed: 2.5 mph; operation pattern: Stop-and-Go; road type: Highway], DS-2 represents the segment of [vehicle speed: 42.5 mph; operation pattern: Speed Up/Slow Down; road type: Highway], and DS-3 represents the segment of [vehicle speed: 52.5 mph; operation pattern: Free Flow; road type: Highway]. From Figure 2-5, it is obvious that the vehicle performance of DS-1 equals the average fuel consumption and emissions of all the driving situations in the twelve Red grids, the vehicle performance of DS-2 equals the average fuel consumption and emissions of all the driving situations in the six Blue grids, and the vehicle performance of DS-3 equals the average fuel consumption and emissions of all the driving situations in the four Green grids. These relationships between driving situations and "driving segments" provide the basis for this thesis to develop the "Driving Segments" vehicle performance matrices to quantify the impacts of worsening traffic.

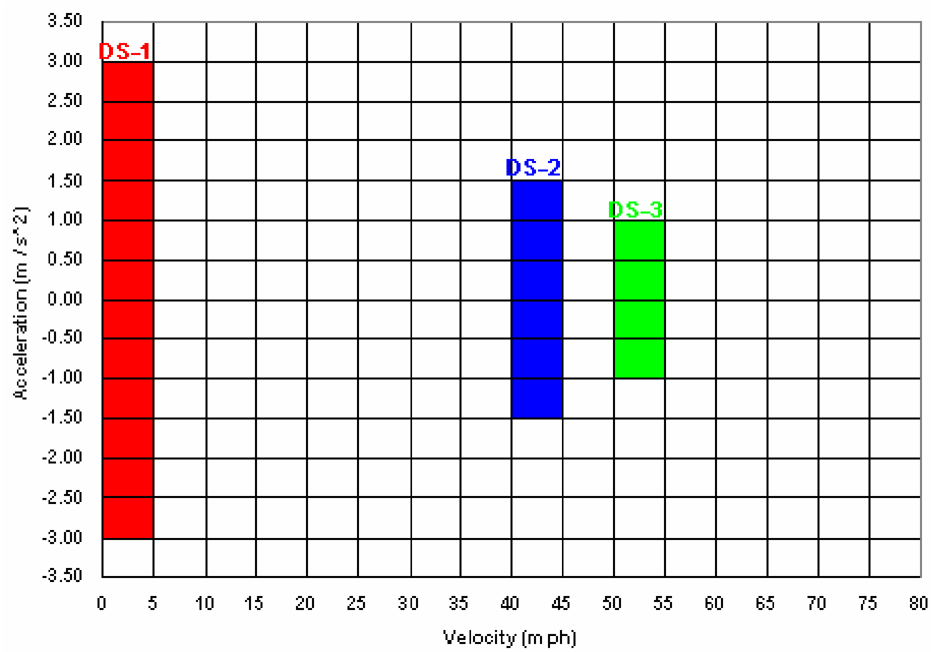

Figure 2-5: Three Sample "Driving Segments" on Highway

2.3 Vehicle Simulation Tool

As discussed in Chapter 1, because of the lack of experimental data, the fuel consumption and emissions of all the driving situations need to be generated by vehicle simulation tools.

Through comparing several professional tools for vehicle simulation (see Table 2-2), this thesis selects ADVISOR 2004 as the data source for instantaneous vehicle characteristics [AVL, 2004; Markel et al., 2002; EPA, 2003; EPA, 2004; ANL, 2005]. Specifically, ADVISOR is designed for rapid analysis of the fuel consumption and emissions of conventional and advanced, light and heavy-duty vehicle models as well as hybrid electric and fuel cell vehicle models.

Table 2-2: Comparison for Vehicle Simulation Tools

Tool	Developer	Output	Feature
ADVISOR 2004	NREL / AVL	Fuel Consumption and Emissions	Vehicle Cycle
MOBILE 6	EPA	Emissions	Vehicle Cycle
MOVES 2004	EPA	Emissions	Vehicle Cycle
GREET 1.6	ANL	Fuel Consumption and Emissions	Fuel Cycle

After defining “driving segments” and choosing simulation tool, this thesis is able to apply the three-step method described in Chapter 1 (see Figure 1-5) to develop the “Driving Segments” vehicle performance matrices:

First, this thesis will use ADVISOR 2004 to simulate the fuel consumption and emissions (gram per second) of different vehicle type under selected standard driving cycles. Considering the fact that driving cycles consist of series of data points representing the velocity and acceleration of a vehicle versus time, ADVISOR 2004 actually produces the fuel consumption and emissions of many possible driving situations.

Second, this thesis will categorize the fuel consumption and emissions of these possible driving situations (from driving cycles) into the 224 grids in the V-A graph. Further, the vehicle performance under each V-A grid (i.e. “V-A” vehicle performance matrices) can be generated by averaging the fuel consumption and emissions of all the driving situations in the same grid.

Third, according to the graphic definition for “driving segments” (see Figures 2-2 ~ 2-4), the vehicle performance under each “driving segment” (i.e. “Driving Segments” vehicle performance matrices, or “Velocity-Pattern” vehicle performance matrices) can finally be developed from the above “V-A” vehicle performance matrices.

Next, this thesis will discuss the simulation objects (vehicle classification and driving cycles) and the simulation results ("V-A" vehicle performance matrices and "Driving Segments" vehicle performance matrices) in detail.

2.4 Simulation Objects

2.4.1 Vehicle Classification

As analyzed in Chapter 1, this thesis will only study the impacts of worsening traffic on light-duty vehicles, which are normally divided into passenger cars and light trucks. In addition, considering the need to develop new vehicle technologies (Hybrid Vehicles, Electric Vehicles, Fuel Cell Vehicles, etc.), this thesis finally defines 13 types of light-duty vehicles as well as corresponding simulation parameters, such as maximum power, peak efficiency and vehicle/cargo mass (see Table 2-3).

Especially, for 10 types of conventional light-duty vehicles, the difference of vehicle performance caused by different transmissions (automatic and manual) will also be compared in this thesis.

2.4.2 Driving Cycles

As mentioned before, because driving cycle consists of series of data points representing the velocity and acceleration of a vehicle versus time, the simulation of fuel consumption and emissions under a standard driving cycle actually provides the vehicle performance of many possible driving situations. In order to get enough driving situations to further calculate the vehicle performance of "driving segments", more than one driving cycle must be considered.

Through comparing the distribution of data points (of each driving cycle) on the V-A graph with the definition of “driving segments” (see Figures 2-2 ~ 2-4), the thesis selects 7 out of 54 standard driving cycles from the database of ADVISOR 2004. These 7 representative driving cycles (ARB02, CSHVR, FTP, LA92, IDLING, INRETS, and OCC) are defined as below and their V-A distribution are shown in Figures 2-6 ~ 2-12.

- ARB02 (Air Resources Board No. 2): a driving cycle developed by the California Air Resources Board, including some city like driving and a period of highway cruising.
- CSHVR (City Suburban Heavy Vehicle Route): a chassis dynamometer test cycle for heavy-duty vehicles developed by the West Virginia University.
- FTP (Federal Test Procedure): a transient test cycle for cars and light trucks performed on a chassis dynamometer, including the simulations for an urban route with frequent stops, aggressive highway driving and the use of air conditioning units.
- LA92 (Los Angeles 92): 1992 test data from Los Angeles that consists of urban / highway mix and can be characterized by aggressive urban driving.
- IDLING: a chassis dynamometer test cycle only representing the idle status of vehicles.
- INRETS (Institut National de REcherche sur les Transports et leur Sécurité): a short urban driving cycle developed by the French national institute for transport and safety research.
- OCC (Orange County Cycle): a chassis dynamometer test cycle for transit buses developed by the West Virginia University.

The above definitions show that not all these 7 driving cycles are developed for light-duty vehicles. However, in order to get the vehicle performance under each "driving segment" (see Figures 2-2 ~ 2-4), this thesis only cares about the distribution of data points on the velocity-acceleration map and therefore it is reasonable to use those driving cycles for heavy-duty vehicles in this thesis.

2.5 Simulation Results

2.5.1 "Velocity-Acceleration" Vehicle Performance Matrices

With the above objects, ADVISOR 2004 needs to simulate the fuel consumption and emissions of 13 light-duty vehicle types under 7 representative driving cycles. In this thesis, all kinds of fuel consumption (gasoline, diesel, electricity and hydrogen) will be converted into gasoline equivalence on the basis of low heating value (LHV), and only the emissions of four major pollutants (CO_2, HC, NO_X and CO) will be considered.

For each vehicle type, 7 driving cycles totally provide 11232 data points (driving situations). In order to analyze so many driving situations, this thesis compiles a special C++ program (see Program A-2-1) to categorize these driving situations into the 224 V-A grids. After that, this program will automatically calculate the average fuel consumption and emissions of all the driving situations in the same grid, and these average fuel consumption and emissions constitute the (approximate) "V-A" vehicle performance matrices (see Table 2-4, the example of Two-seater Car with automatic transmission).

Table 2-3: Vehicle Classification and Simulation Parameters

Vehicle Classification				No.	Drivetrain	Fuel Converter	MaxPower (kW)	Peak Efficiency	Transmission	Mass/Cargo (kg)
Conventional	Passenger Cars	Two-seater Car		1	Conventional	IC-SI-Gasoline	41	0.34	Auto/Manual	984/136
		Sedan	Subcompact	2	Conventional	IC-SI-Gasoline	63	0.34	Auto/Manual	1319/136
			Compact	3	Conventional	IC-SI-Gasoline	63	0.34	Auto/Manual	1466/136
			Midsize	4	Conventional	IC-SI-Gasoline	63	0.34	Auto/Manual	1541/136
			Large	5	Conventional	IC-SI-Gasoline	63	0.34	Auto/Manual	1492/136
	Light Trucks	Pickup	Small	6	Conventional	IC-SI-Gasoline	102	0.29	Auto/Manual	1573/136
			Large	7	Conventional	IC-SI-Gasoline	102	0.29	Auto/Manual	1849/136
		Van	Small	8	Conventional	IC-SI-Gasoline	102	0.29	Auto/Manual	1970/136
			Large	9	Conventional	IC-SI-Gasoline	102	0.29	Auto/Manual	2010/136
		SUV		10	Conventional	IC-SI-Gasoline	144	0.34	Auto/Manual	1924/136
New	Passenger Cars	Hybrid: Prius (midsize)		11	Hybrid	IC-SI-Gasoline	43	0.39	Auto=Manual	1332/136
		EV		12	Electricity	-	75	0.92	Auto=Manual	1144/136
		FCV		13	Fuel Cell	-	50	0.60	Auto=Manual	1380/136

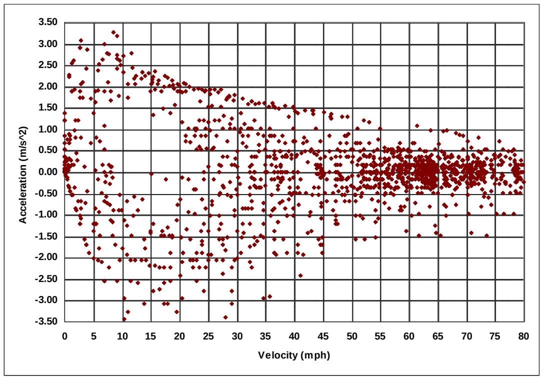

Figure 2-6: V-A Distribution for ARB02

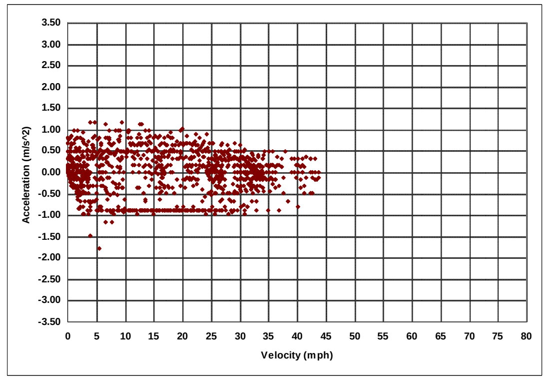

Figure 2-7: V-A Distribution for CSHVR

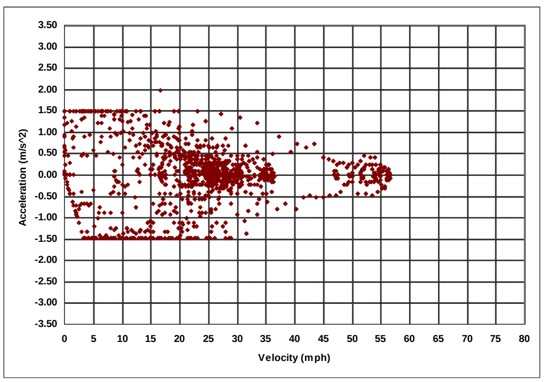

Figure 2-8: V-A Distribution for FTP

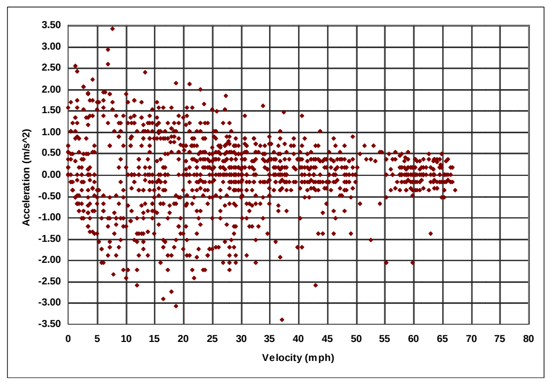

Figure 2-9: V-A Distribution for LA-92

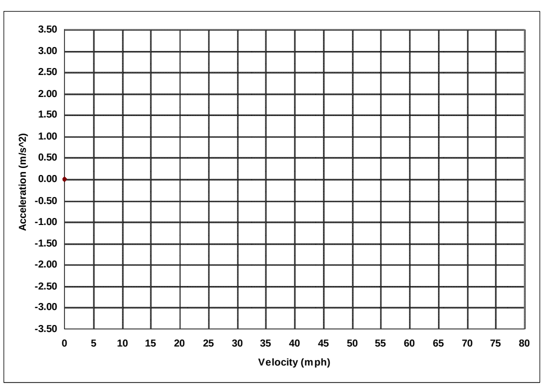

Figure 2-10: V-A Distribution for IDLING

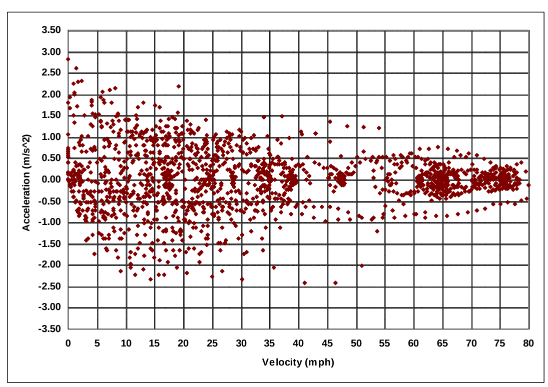

Figure 2-11: V-A Distribution for INRETS

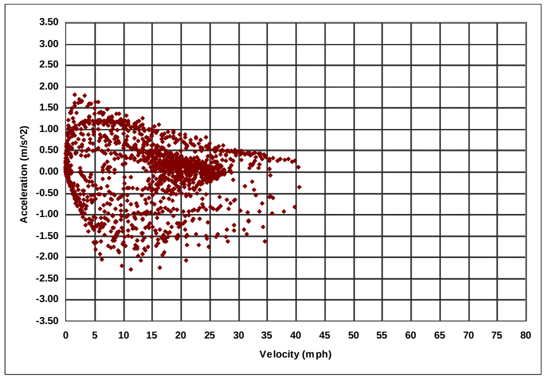

Figure 2-12: V-A Distribution for OCC

Table 2-4: "V-A" Vehicle Performance Matrix for Two-seater Car (Automatic Transmission)

Velocity (mph)	Accel (m/s^2)	Fuel (g/s)	CO_2 (g/s)	HC (g/s)	NO_x (g/s)	CO (g/s)
[0, 5)	[-3.5, -3.0)	0.119	0.371	0.000	0.000	0.000
[0, 5)	[-3.0, -2.5)	0.125	0.388	0.000	0.000	0.000
[0, 5)	[-2.5, -2.0)	0.123	0.385	0.000	0.000	0.000
[0, 5)	[-2.0, -1.5)	0.127	0.390	0.000	0.000	0.001
[0, 5)	[-1.5, -1.0)	0.130	0.397	0.000	0.000	0.003
[0, 5)	[-1.0, -0.5)	0.140	0.424	0.001	0.000	0.004
[0, 5)	[-0.5, 0.0)	0.200	0.599	0.002	0.001	0.007
[0, 5)	[0.0, 0.5)	0.145	0.426	0.003	0.001	0.009
[0, 5)	[0.5, 1.0)	0.308	0.925	0.003	0.002	0.010
[0, 5)	[1.0, 1.5)	0.331	0.992	0.005	0.003	0.011
[0, 5)	[1.5, 2.0)	0.367	1.072	0.007	0.004	0.024
[0, 5)	[2.0, 2.5)	0.345	1.045	0.003	0.003	0.008
[0, 5)	[2.5, 3.0)	0.358	1.101	0.001	0.001	0.002
[0, 5)	[3.0, 3.5]	0.820	2.468	0.002	0.002	0.040
[5, 10)	[-3.5, -3.0)	0.127	0.391	0.000	0.000	0.001
[5, 10)	[-3.0, -2.5)	0.130	0.399	0.000	0.000	0.001
[5, 10)	[-2.5, -2.0)	0.129	0.397	0.000	0.000	0.001
[5, 10)	[-2.0, -1.5)	0.145	0.441	0.001	0.000	0.003
[5, 10)	[-1.5, -1.0)	0.149	0.447	0.001	0.000	0.006
[5, 10)	[-1.0, -0.5)	0.157	0.472	0.001	0.000	0.005
[5, 10)	[-0.5, 0.0)	0.188	0.568	0.002	0.000	0.005
[5, 10)	[0.0, 0.5)	0.303	0.908	0.002	0.002	0.013
[5, 10)	[0.5, 1.0)	0.419	1.239	0.007	0.005	0.022
[5, 10)	[1.0, 1.5)	0.600	1.774	0.006	0.006	0.038
[5, 10)	[1.5, 2.0)	0.579	1.642	0.006	0.005	0.081
[5, 10)	[2.0, 2.5)	0.705	2.143	0.002	0.002	0.018
[5, 10)	[2.5, 3.0)	0.855	2.500	0.009	0.005	0.072
[5, 10)	[3.0, 3.5]	1.108	3.241	0.010	0.005	0.097
……	……	……	……	……	……	……
[75, 80]	[-3.5, -3.0)	0.290	0.912	0.004	0.002	0.000
[75, 80]	[-3.0, -2.5)	0.090	0.293	0.000	0.000	0.000
[75, 80]	[-2.5, -2.0)	0.188	0.580	0.001	0.000	0.000
[75, 80]	[-2.0, -1.5)	0.470	1.436	0.001	0.000	0.008
[75, 80]	[-1.5, -1.0)	0.950	2.874	0.002	0.001	0.034
[75, 80]	[-1.0, -0.5)	1.358	4.114	0.003	0.002	0.045
[75, 80]	[-0.5, 0.0)	1.751	5.300	0.003	0.004	0.060
[75, 80]	[0.0, 0.5)	1.835	5.546	0.003	0.003	0.070
[75, 80]	[0.5, 1.0)	1.591	4.801	0.003	0.003	0.065
[75, 80]	[1.0, 1.5)	0.362	1.084	0.003	0.000	0.014
[75, 80]	[1.5, 2.0)	3.369	10.137	0.004	0.003	0.163
[75, 80]	[2.0, 2.5)	2.012	6.070	0.005	0.005	0.083
[75, 80]	[2.5, 3.0)	1.889	5.904	0.000	0.000	0.000
[75, 80]	[3.0, 3.5]	1.765	5.738	0.000	0.000	0.000

Especially, for a few grids into which no driving situation falls, their associated fuel consumption and emissions will be linearly interpolated or extrapolated from the vehicle performance of adjacent grids. Moreover, all these interpolations and extrapolations will be taken along both V axis and A axis and then be averaged to improve the accuracy.

2.5.2 "Driving Segments" Vehicle Performance Matrices

Combining the "V-A" vehicle performance matrices with the graphic definition of "driving segments" (see Figures 2-2 ~ 2-4), the average fuel consumption and emissions in each "driving segment" can be finally developed into the "Driving Segments" (or "Velocity-Pattern") vehicle performance matrices. Table 2-5 gives the example of Two-seater Car with automatic transmission under the "Free Flow" pattern.

Table 2-5: "Driving Segments" Vehicle Performance Matrix for Two-seater Car (Automatic, Free Flow, Time)

Based on Time														
Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway	1.213	1.100	1.066	1.113										
Suburban						1.368	1.129	0.909						
Urban								0.825	0.652	0.571				
	Emissions-CO_2 (g/s)													
Highway	3.679	3.337	3.236	3.222										
Suburban						4.146	3.423	2.753						
Urban								2.499	1.974	1.720				
	Emissions-HC (g/s)													
Highway	0.002	0.002	0.002	0.006										
Suburban						0.002	0.002	0.002						
Urban								0.002	0.002	0.003				
	Emissions-NO_x (g/s)													
Highway	0.003	0.003	0.002	0.004										
Suburban						0.003	0.002	0.002						
Urban								0.002	0.003	0.003				
	Emissions-CO (g/s)													
Highway	0.038	0.033	0.031	0.127										
Suburban						0.044	0.035	0.030						
Urban								0.026	0.021	0.023				

As pointed out before, the units for fuel consumption and emissions in Table 2-5 are "gram per second" because the definition of driving cycles (data points representing driving situations versus time) determines the output of ADVISOR 2004. Divided by the average vehicle speed for each segments, the units of vehicle performance can be easily changed into "gram per mile" (see Table 2-6), which may be more useful to analyze the energy and environmental impacts of worsening traffic in the next two chapters.

Table 2-6: “Driving Segments” Vehicle Performance Matrix for Two-seater Car (Automatic, Free Flow, Mileage)

Based on Mileage														
Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway	64.707	63.346	66.725	76.337										
Suburban						115.866	108.348	100.675						
Urban								91.329	85.309	91.360				
	Emissions-CO_2 (g/mile)													
Highway	196.227	192.226	202.586	220.920										
Suburban						351.215	328.632	304.892						
Urban								276.831	258.371	275.120				
	Emissions-HC (g/mile)													
Highway	0.120	0.130	0.125	0.377										
Suburban						0.194	0.192	0.208						
Urban								0.203	0.262	0.400				
	Emissions-NO_x (g/mile)													
Highway	0.147	0.158	0.141	0.274										
Suburban						0.230	0.228	0.222						
Urban								0.222	0.349	0.427				
	Emissions-CO (g/mile)													
Highway	2.027	1.901	1.941	8.674										
Suburban						3.751	3.372	3.365						
Urban								2.862	2.705	3.627				

All the “Driving Segments” vehicle performance matrices for 13 light-duty vehicle types (both time-based and mileage-based) have been summarized in Tables A-2-1 ~ A-2-23 (see the Appendix).

2.6 Summary

This Chapter gives the detailed definition of “driving segments” and establishes the relationship between driving situations and “driving segments” on the V-A graph.

With the aid from ADVISOR 2004, this Chapter also develops the time-based and mileage-based “Driving Segments” vehicle performance matrices for 13 light-duty vehicle types, which provide the solid basis for analyzing the impacts of worsening traffic in the next two chapters.

CHAPTER 3: IMPACTS OF WORSENING TRAFFIC ON INDIVIDUAL VEHICLES

3.1 Introduction

Mobile sources have been identified as major contributors to energy and environmental problems in the U.S. [EIA, 2005]. Thus, it is important that there be accurate fuel consumption and emissions inventories for mobile sources, especially for light-duty vehicles, which constitute the greatest proportion of the U.S. on-road vehicle fleet. However, the fuel consumption and emissions of light-duty vehicles are generally tested under standard driving cycles, which can not well describe the real-world driving patterns influenced by worsening traffic [Samuel et al., 2003].

With the "Driving Segments" (or "Velocity-Pattern") matrices developed in Chapter 2, vehicle performance under any driving situations can be easily calculated. In other words, the "on-road" fuel consumption and emissions of light-duty vehicles can be quantified through specific "driving segments" stemming from real traffic situations. Further, the change of individual vehicle performance caused by worsening traffic can also be investigated.

For simplicity, this Chapter first analyzes individual vehicle performance on the basis of single commute with the "Velocity-Acceleration" vehicle performance matrices. After that, a rough traffic model is assumed to reflect the comprehensive effects of worsening traffic on all kinds of commutes. Through linking this traffic assumption and the "Driving Segments" vehicle performance matrices, the "on-road" fuel consumption and emissions of 13 light-duty vehicle types as well as the impacts of worsening traffic on vehicle performance are examined.

3.2 Individual Vehicle and Single Commute

In order to study the individual vehicle performance over single commute, this Chapter defines a typical daily work commute from home to office and three sets of driving situations determined by traffic congestion on this commute. Through adjusting the proportion of different driving situation sets among annual driving trips, three scenarios for traffic change from 2005 to 2010 are also defined. Combining these commute and traffic definitions with the "Velocity-Acceleration" vehicle performance matrices, the annual fuel consumption and emissions of individual vehicle under different traffic scenarios can be calculated. For simplicity, the following assumptions have been made:

- Only four types of light-duty vehicle are considered here: Compact Sedan, Midsize Sedan, SUV, and Hybrid (Toyota Prius);
- Only light-duty vehicles with automatic transmission are considered;
- The impacts of technology development on vehicle performance are ignored during this five-year-long period (2005 ~ 2010).

3.2.1 Commute Description

From home to office, the daily work commute consists of one urban section (side-street), two suburban sections (artery) and one highway section which are 18.6 miles totally in length. Traffic light, stop sign and highway ramp have also been included in this commute to best simulate the real traffic situations (see Figure 3-1).

The traffic situations on this commute can be roughly classified into three grades: “normal”, “busy” and “snarled”, which represent increasingly worse congestion levels. Based on several real cases, three sets of driving situations including velocity, acceleration and time duration under “normal”, “busy” and “snarled” traffic situations are defined in Table 3-1.

In addition, Figure 3-1 and Figure 3-2 graphically describe these three sets of driving situations from different views (velocity-distance and velocity-time).

Table 3-1: Three Sets of Driving Situations

		SIDE-STREET		ARTERY		RAMP	HIGHWAY		RAMP	ARTERY		TOTAL	
		Run	*Idle*	*Run*	*Idle*		*Run*	*Idle*		*Run*	*Idle*		
DISTANCE (mile)		2.0	0.0	3.0	0.0	0.3	10.0	0.0	0.3	3.0	0.0	***18.6***	***miles***
NORMAL	***Velocity (mph)***	35.0	0.0	45.0	0.0	55.0	65.0	0.0	55.0	45.0	0.0		
	Time (min)	3.4	1.0	4.0	0.0	0.3	9.2	0.0	0.3	4.0	0.0	***22.3***	***minutes***
	Max Accel. (mph/s)	3.7	0.0	5.0	0.0	1.0	2.7	0.0	1.0	5.0	0.0		
BUSY	***Velocity (mph)***	20.0	0.0	30.0	0.0	40.0	50.0	0.0	40.0	30.0	0.0		
	Time (min)	6.0	2.0	6.0	1.0	0.5	12.0	0.0	0.5	6.0	1.0	***34.9***	***minutes***
	Max Accel. (mph/s)	3.7	0.0	5.7	0.0	0.7	3.4	0.0	0.7	5.7	0.0		
SNARLED	***Velocity (mph)***	10.0	0.0	15.0	0.0	27.5	40.0	0.0	27.5	15.0	0.0		
	Time (min)	12.0	3.0	12.0	2.0	0.7	15.0	2.0	0.7	12.0	2.0	***61.3***	***minutes***
	Max Accel. (mph/s)	3.7	0.0	5.8	0.0	0.6	6.1	0.0	0.6	5.8	0.0		

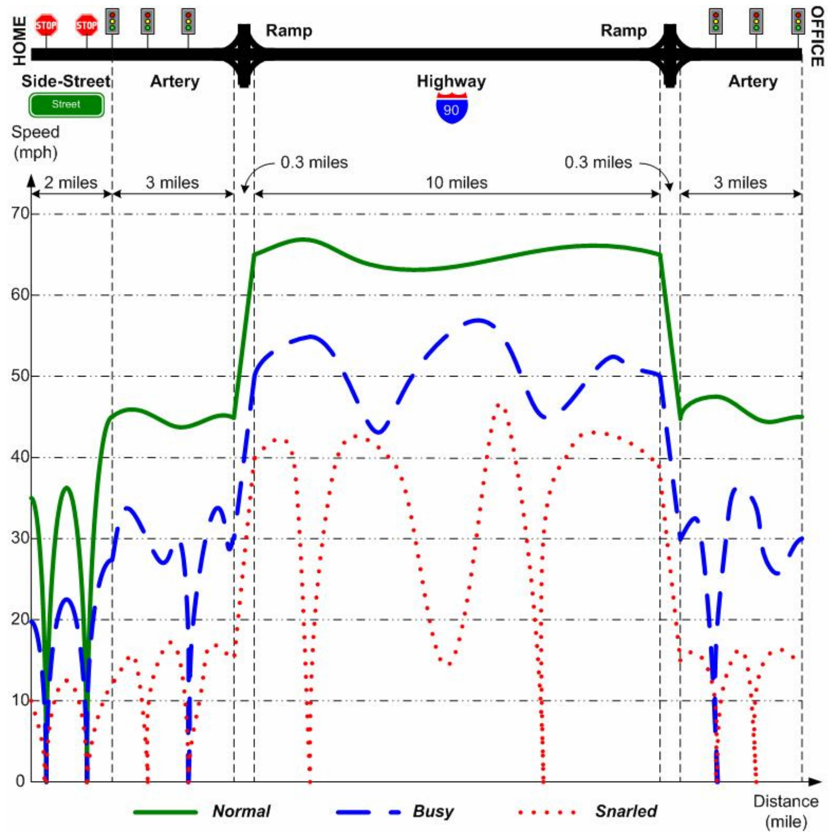

Figure 3-1: Driving Situation Description (Velocity-Distance)

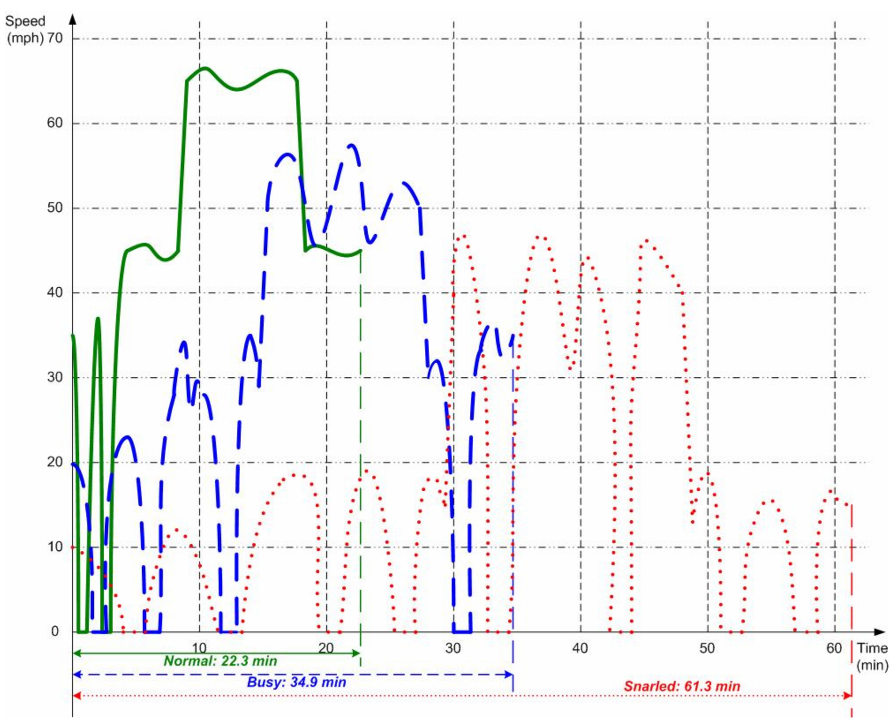

Figure 3-2: Driving Situation Description (Velocity-Time)

3.2.2 Traffic Assumptions

This daily work commute only considers traveling from home to office, and therefore it is assumed that there are 240 trips on this commute per year, after deducting all the holidays. Further, according to practical experience, it is also assumed that in 2005, 70% of these 240 trips belong to "normal" traffic situation, 20% of these trips belong to "busy" traffic situation, and the remaining 10% of these trips fall into "snarled" traffic situation.

Based on the above two assumptions, this Chapter defines three scenarios for the traffic change from 2005 to 2010, namely, "same", "bad" and "horrible" (see Table 3-2 and Figure 3-3). From "same" scenario to "horrible" scenario, it is obvious that the traffic situation in 2010 becomes worse, which is consistent with existing research on the trend of traffic congestion [TTI, 2005].

Table 3-2: Traffic Assumptions for 2005 and 2010

		NORMAL		BUSY		SNARLED	
		percent	trips	percent	trips	percent	trips
2005		70%	168	20%	48	10%	24
2010	**Same**	70%	168	20%	48	10%	24
	Bad	50%	120	30%	72	20%	48
	Horrible	30%	72	40%	96	30%	72

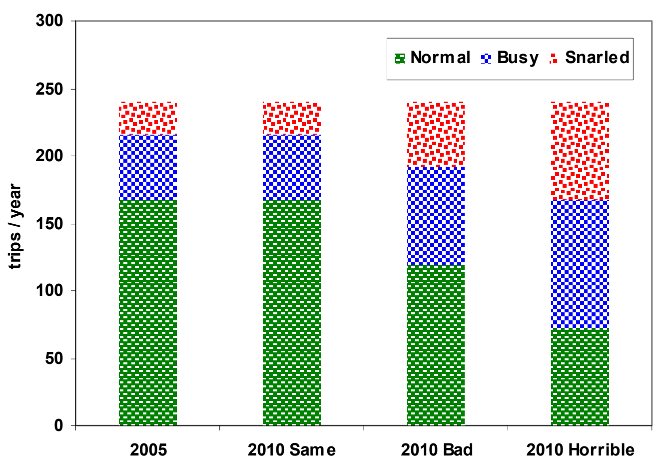

Figure 3-3: Traffic Assumptions for 2005 and 2010

3.2.3 Vehicle Performance Assessment

Combining the above three sets of driving situations and traffic assumptions with the "Velocity-Acceleration" vehicle performance matrices developed in Chapter 2, the "on-road" fuel consumption and emissions of four common light-duty vehicle types under different traffic scenarios can be quantified through the following two steps:

First, calculating the "per-trip" fuel consumption and emissions from the "Velocity-Acceleration" matrices and driving situation definitions. As discussed in Chapter 2, every common driving situation can be categorized into one of the 224 grids on the velocity-acceleration graph (velocity: 0 ~ 80 mph, acceleration: -3.5 ~ 3.5 m / s^2, see Figure 3-4), and the "Velocity-Acceleration" matrices, which are measured in time units, give the average fuel consumption and emissions for all the driving situations in the same grid (see Table 3-3, the example of Compact Sedan). On the other hand, the driving situations and their time duration for "normal", "busy" and "snarled" trips are described by the driving situation definitions (see Table 3-1 and Figures 3-1, 3-2). Therefore, the "per-trip" fuel consumption and emissions of individual vehicle (see Table 3-4, the example of Compact Sedan) can be generated by multiplying the vehicle performance in "Velocity-Acceleration" matrices and the corresponding time duration in driving situation definitions.

For instance, according to the definition for the "normal" trip in Figures 3-1 and 3-2, the driving situations on the side-street can be represented with the grey areas in Figure 3-4. Furthermore, the grey values in Table 3-3 and Table 3-1 respectively provide the vehicle performance and time durations of these driving situations. Multiplying the grey values in these two tables, the fuel consumption and emissions on the side-street during the "normal" trip can be calculated and then summarized in the grey area of Table 3-4.

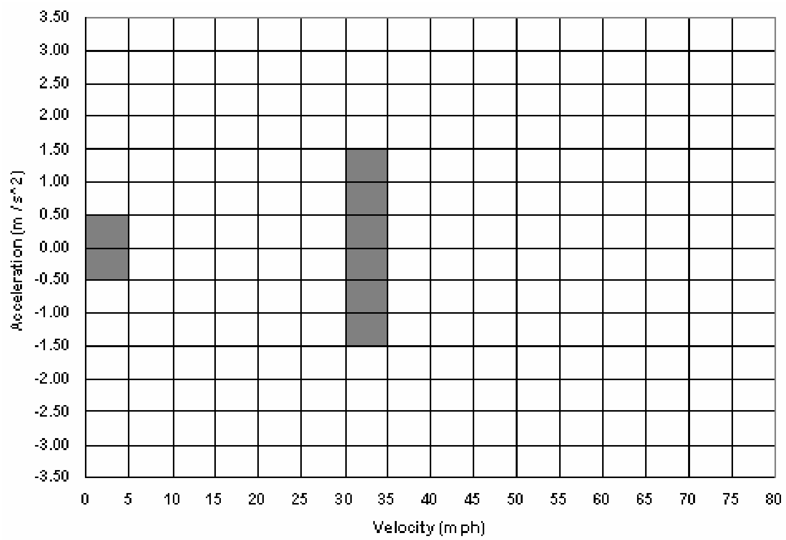

Figure 3-4: Velocity-Acceleration Graph for Vehicle Performance

Table 3-3: Velocity-Acceleration Matrices for Compact Sedan

Velocity (mph)	Accel (m/s^2)	Gasoline (g/s)	CO_2 (g/s)	HC (g/s)	NO_x (g/s)	CO (g/s)
[0, 5)	[-3.50, -3.00)	0.187	0.582	0.000	0.000	0.000
[0, 5)	[-3.00, -2.50)	0.196	0.605	0.000	0.000	0.000
[0, 5)	[-2.50, -2.00)	0.192	0.598	0.000	0.000	0.000
[0, 5)	[-2.00, -1.50)	0.198	0.608	0.000	0.000	0.001
[0, 5)	[-1.50, -1.00)	0.203	0.618	0.000	0.000	0.004
[0, 5)	[-1.00, -0.50)	0.220	0.668	0.001	0.000	0.005
[0, 5)	[-0.50, 0.00)	0.285	0.862	0.001	0.000	0.008
[0, 5)	[0.00, 0.50)	0.229	0.687	0.002	0.000	0.009
[0, 5)	[0.50, 1.00)	0.383	1.160	0.002	0.001	0.010
[0, 5)	[1.00, 1.50)	0.423	1.276	0.003	0.001	0.013
[0, 5)	[1.50, 2.00)	0.478	1.432	0.005	0.002	0.019
[0, 5)	[2.00, 2.50)	0.442	1.344	0.002	0.001	0.010
[0, 5)	[2.50, 3.00)	0.464	1.429	0.001	0.000	0.002
[0, 5)	[3.00, 3.50)	0.487	1.514	0.000	0.000	0.000
…	…	…	…	…	…	…
[30, 35)	[-3.50, -3.00)	0.208	0.637	0.000	0.000	0.002
[30, 35)	[-3.00, -2.50)	0.194	0.595	0.000	0.000	0.001
[30, 35)	[-2.50, -2.00)	0.199	0.611	0.000	0.000	0.001
[30, 35)	[-2.00, -1.50)	0.199	0.606	0.000	0.000	0.003
[30, 35)	[-1.50, -1.00)	0.206	0.631	0.000	0.000	0.002
[30, 35)	[-1.00, -0.50)	0.286	0.877	0.000	0.000	0.002
[30, 35)	[-0.50, 0.00)	0.453	1.384	0.001	0.001	0.006
[30, 35)	[0.00, 0.50)	0.928	2.840	0.003	0.003	0.011
[30, 35)	[0.50, 1.00)	1.762	5.411	0.003	0.005	0.012
[30, 35)	[1.00, 1.50)	2.642	8.121	0.004	0.007	0.016
[30, 35)	[1.50, 2.00)	3.795	11.427	0.033	0.026	0.122
[30, 35)	[2.00, 2.50)	5.300	16.051	0.034	0.031	0.133
[30, 35)	[2.50, 3.00)	4.931	14.863	0.042	0.032	0.149
[30, 35)	[3.00, 3.50)	4.563	13.675	0.049	0.034	0.165
…	…	…	…	…	…	…
[75, 80)	[3.00, 3.50)	2.091	7.060	0.000	0.000	0.000

Table 3-4: "Per-Trip" Fuel Consumption and Emissions of Compact Sedan

		SIDE-STREET	ARTERY	HIGHWAY	RAMP	TOTAL
NORMAL	*Gasoline (g)*	230.631	683.760	750.462	36.877	1701.730
	CO_2 (g)	706.950	2066.580	2309.815	113.184	5196.529
	HC (g)	0.467	4.800	0.831	0.098	6.196
	NO_x (g)	0.549	3.900	1.523	0.098	6.070
	CO (g)	2.190	18.900	3.046	0.275	24.411
BUSY	*Gasoline (g)*	262.980	1029.336	1084.560	37.827	2414.703
	CO_2 (g)	799.200	3115.500	3265.560	116.235	7296.495
	HC (g)	1.260	6.804	8.880	0.054	16.998
	NO_x (g)	0.840	5.688	7.440	0.081	14.049
	CO (g)	5.820	27.012	36.120	0.243	69.195
SNARLED	*Gasoline (g)*	334.860	997.392	1795.290	45.753	3173.295
	CO_2 (g)	1013.490	3030.024	5432.640	139.850	9616.004
	HC (g)	1.950	4.680	12.105	0.157	18.892
	NO_x (g)	0.960	3.600	9.975	0.157	14.692
	CO (g)	9.210	22.200	46.620	0.707	78.737

Second, calculating the annual fuel consumption and emissions from the "per-trip" vehicle performance and traffic assumptions. Once the "per-trip" fuel consumption and emissions of individual vehicle are calculated out, the annual fuel consumption and emissions can be obtained by aggregating the products of the "per-trip" vehicle performance (see Table 3-4) and the corresponding trip amount defined in the traffic assumptions (see Table 3-2). Table 3-5 gives the calculation results for Compact Sedan.

Table 3-5: Annual Morning Commute Fuel Consumption and Emissions of Compact Sedan

	2010 SCENARIOS			Δq
	Same	*Bad*	*Horrible*	
Gasoline (tonne/year)	0.478	0.530	0.583	0.052
CO_2 (tonne/year)	1.454	1.610	1.767	0.156
HC (kg/year)	2.310	2.874	3.438	0.564
NO_x (kg/year)	2.047	2.445	2.844	0.398
CO (kg/year)	9.312	11.691	14.069	2.379

Through the above two steps, the annual vehicle performance for each of these four light-duty vehicle types can be quantified (see Figures 3-5 ~ 3-14).

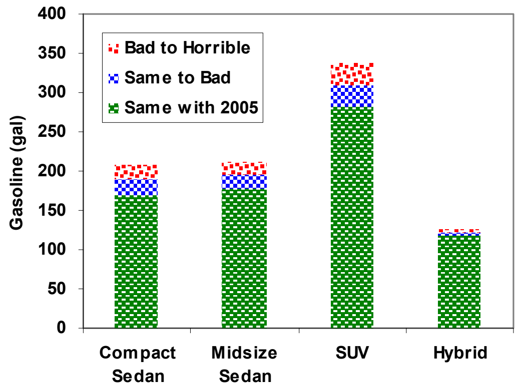

Figure 3-5: Annual Fuel Consumption Change in 2010

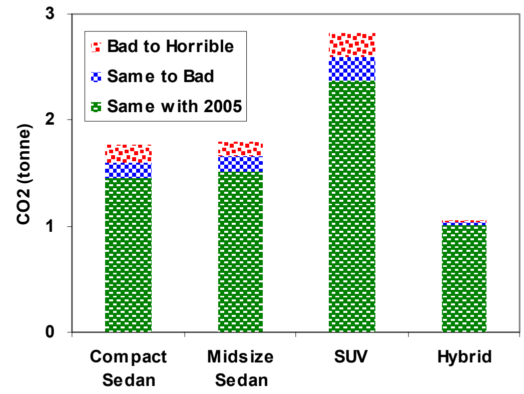

Figure 3-6: Annual CO_2 Emission Change in 2010

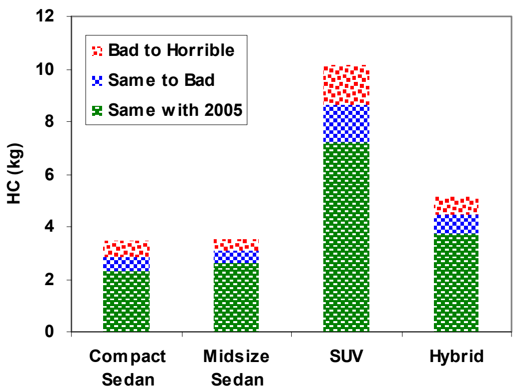

Figure 3-7: Annual HC Emission Change in 2010

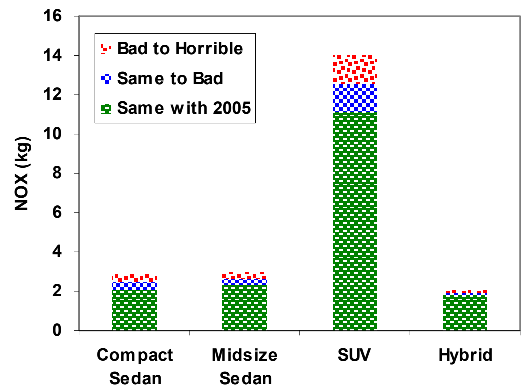

Figure 3-8: Annual NO_X Emission Change in 2010

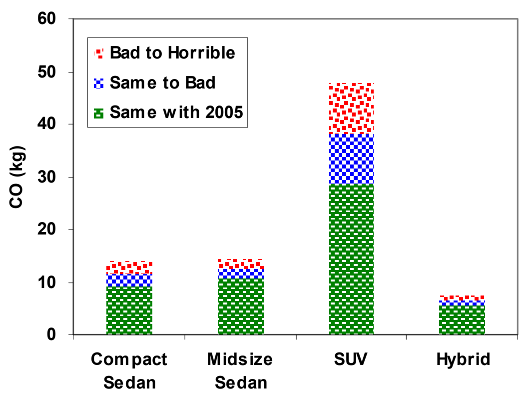

Figure 3-9: Annual CO Emission Change in 2010

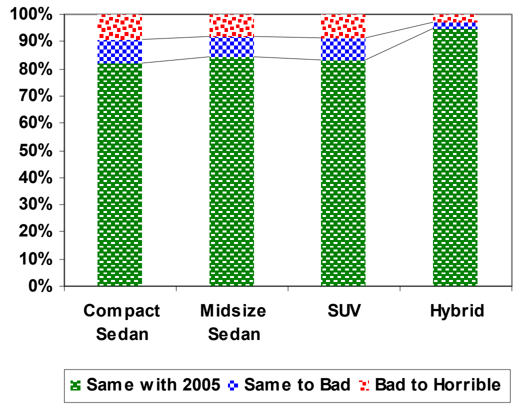

Figure 3-10: Annual Fuel Percentage Change in 2010

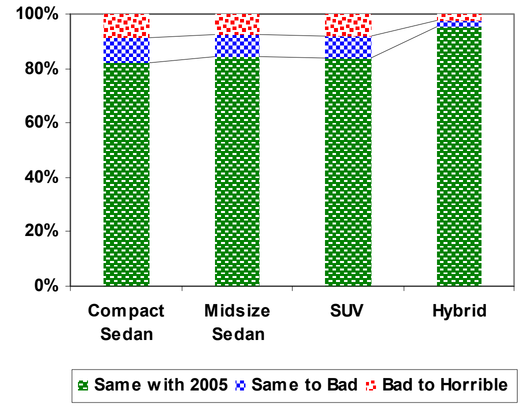

Figure 3-11: Annual CO_2 Percentage Change in 2010

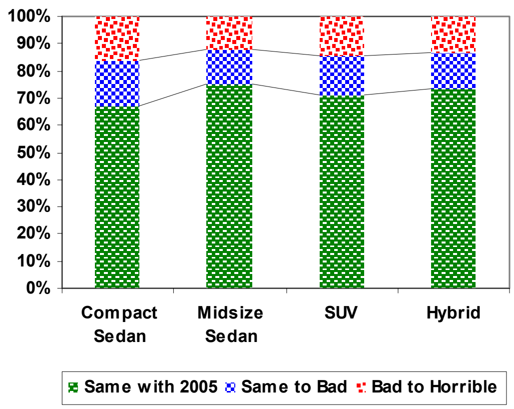

Figure 3-12: Annual HC Percentage Change in 2010

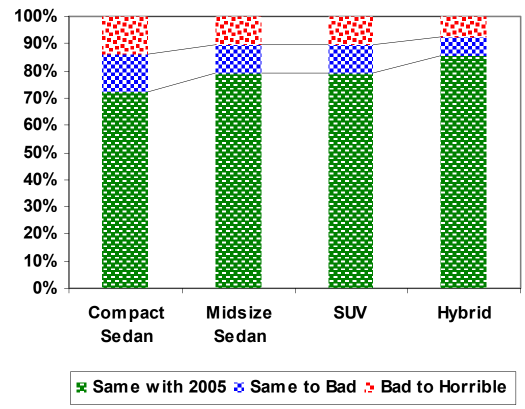

Figure 3-13: Annual NO_X Percentage Change in 2010

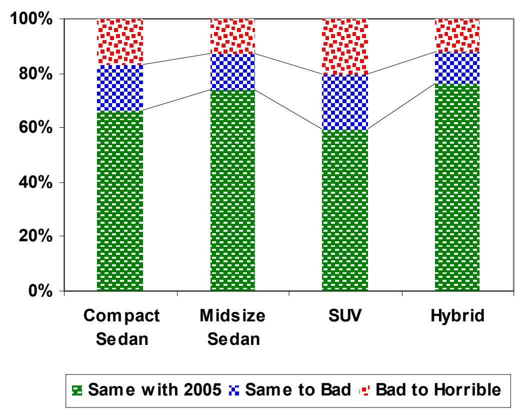

Figure 3-14: Annual CO Percentage Change in 2010

Specifically, Figures 3-5 ~ 3-9 account for the absolute changes of vehicle performance among three traffic scenarios in 2010 (“same”, “bad” and “horrible”), while Figures 3-10 ~ 3-14 account for the relative changes (percentage changes) of vehicle performance among traffic scenarios in 2010 (“same”, “bad” and “horrible”).

Based upon these graphs, several important conclusions are made as below:

- From the “same” scenario, to the “bad” scenario, and to the “horrible” scenario, the absolute changes of SUV’s fuel consumption (29 gallons / year) and CO_2 emission (0.227 tonne / year) are the largest among four vehicle types, whereas the absolute changes of Hybrid’s fuel consumption (3 gallons / year) and CO_2 emission (0.025 tonne / year) are the smallest (see Figures 3-5 and 3-6);
- From the “same” scenario, to the “bad” scenario, and to the “horrible” scenario, the percentage changes of Compact Sedan’s fuel consumption (8.9%) and CO_2 (8.8%) emission are the largest among four vehicle types, whereas the percentage changes of Hybrid’s fuel consumption (2.6%) and CO_2 (2.4%) emission are the smallest (see Figures 3-10 and 3-11);
- Summing up the above points, worsening traffic has the smallest impacts on the energy and environmental (CO_2 mainly) performance of Hybrid, as well as the largest impacts on SUV (in terms of absolute changes) and Compact Sedan (in terms of percentage changes). In other words, Hybrid is the most competitive vehicle type when traffic congestion becomes worse and worse.

3.2.4 “On-road” Fuel Economy

From the annual fuel consumption of four vehicle types under three traffic scenarios in 2010 (see Figure 3-5), it’s straightforward to get the relevant fuel costs on this specific work commute (see Figures 3-15 ~ 3-20).

According to these graphs, with various assumptions for gasoline price in 2010 ($1.5 / gallon ~ $4.0 / gallon), the additional fuel cost raised by worsening traffic for SUV ranges from $86 ~ $228, which are the highest among four vehicle types; while Hybrid's additional fuel cost ranges from $10 ~ $26, which are the lowest.

That is to say, if the traffic congestion in 2010 becomes worse than that in 2005, the people using Hybrid will save $76 ~ $ 202 per year on their work commute (see Figure 3-1), compared to other people using SUV.

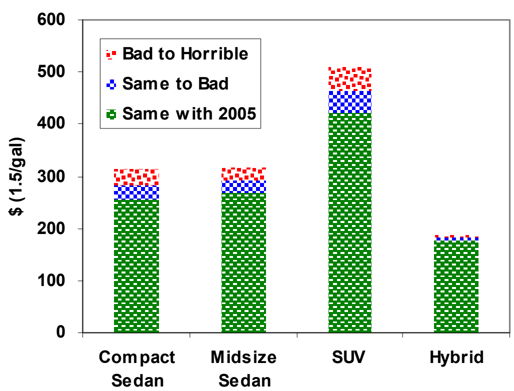

Figure 3-15: Annual Fuel Cost in 2010 ($1.5 / gallon)

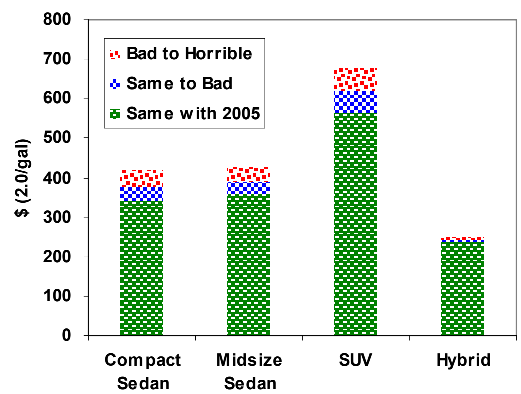

Figure 3-16: Annual Fuel Cost in 2010 ($2.0 / gallon)

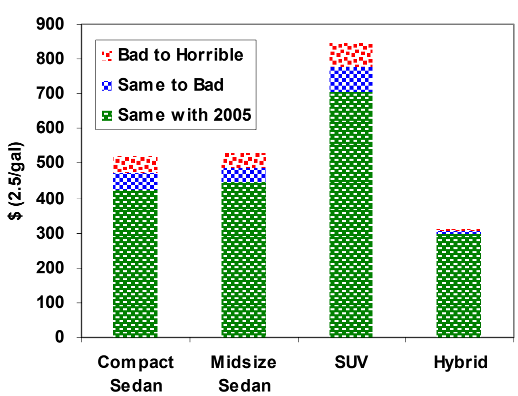

Figure 3-17: Annual Fuel Cost in 2010 ($2.5 / gallon)

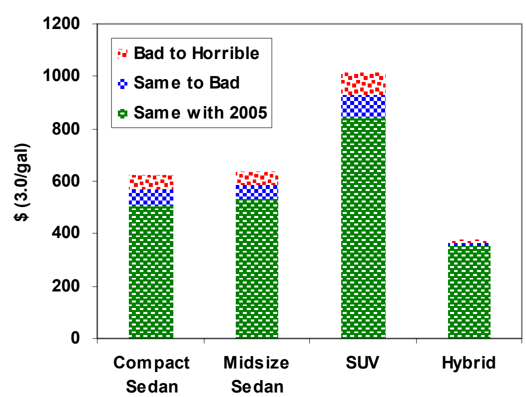

Figure 3-18: Annual Fuel Cost in 2010 ($3.0 / gallon)

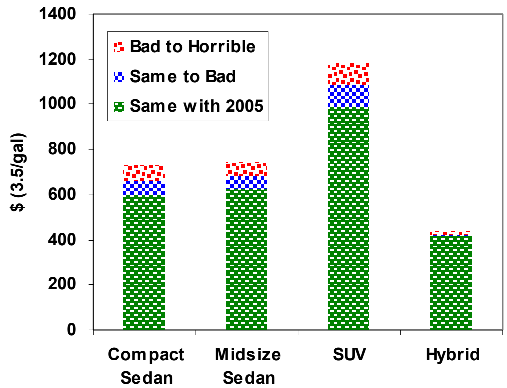

Figure 3-19: Annual Fuel Cost in 2010 ($3.5 / gallon)

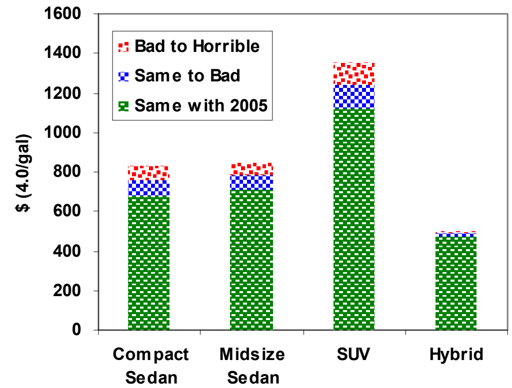

Figure 3-20: Annual Fuel Cost in 2010 ($4.0 / gallon)

Moreover, integrating the annual fuel consumption with the defined commute distance (see Table 3-1 and Figure 3-1), the average fuel economy of four vehicle types for the specific work commute under three traffic scenarios in 2010 can also be calculated (see Table 3-6). In order to distinguish these fuel economy data from those developed in the Fuel Economy Guide (FEG) [DOE and EPA, 2005], this Chapter names the fuel economy data listed in Table 3-6 as "On-road" fuel economy, which means these data directly coming from real driving situations. Figure 3-21 further visualizes the difference between the "On-road" fuel economy and the "FEG" fuel economy. Especially, the "FEG" fuel economy assumes 15,000 miles of travel a year (55% under city driving conditions and 45% under highway driving conditions).

Table 3-6: "On-road" Fuel Economy for Work Commute in 2010 (miles per gallon, MPG)

	2010 SCENARIOS		
	Same	*Bad*	*Horrible*
Compact	26	24	21
Midsize	25	23	21
SUV	16	14	13
Hybrid	38	37	36

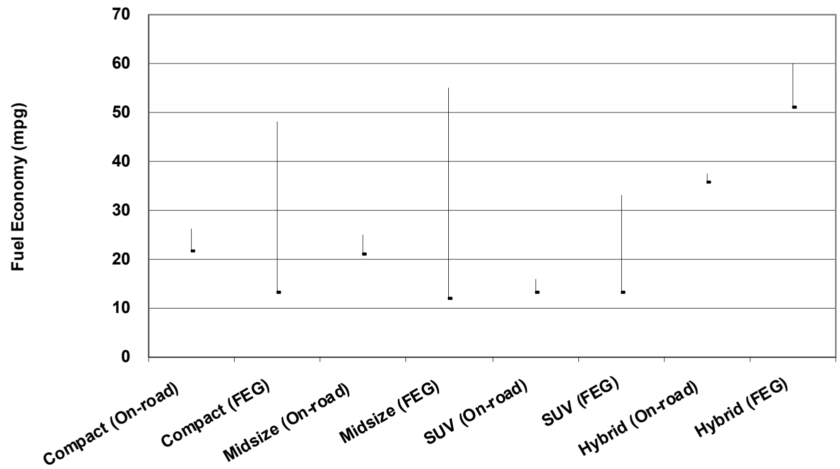

Figure 3-21: Comparison between "On-road" and "FEG" Fuel Economy

From Figure 3-21, it can be concluded that the "On-road" fuel economy for SUV and Hybrid (especially Hybrid) are much lower than their fuel economy predicted in the Fuel Economy Guide. This conclusion supports the wide-spread doubt about the inconsistency between standard driving cycles and real-world driving situations.

On the other hand, although the fuel economy of Hybrid is likely to be overestimated by DOE and EPA, Hybrid is still the most competitive vehicle type on energy and environmental performance under worsening traffic (see 3.2.3).

3.3 Individual Vehicle and All Commutes

In the above part, the impacts of worsening traffic on the fuel consumption and emissions of individual vehicles have been studied with the example of single work commute. However, the real-world driving situations consist of not only the work commute but also other kinds of commutes, such as shopping trips, vacation trips and so on. Also, driving habits vary a lot with different people. In order to reflect the comprehensive effects of worsening traffic on all these commutes, this Chapter adopts the traffic model established in the 2005 Urban Mobility Report [TTI, 2005]. Based on this model, the “On-road” fuel consumption and emissions of 13 light-duty vehicle types under different traffic congestion can be roughly calculated with the “Driving Segments” vehicle performance matrices developed in Chapter 2.

3.3.1 Traffic Assumption

The 2005 Urban Mobility Report assumes a model to quantify the change of traffic congestion with time. In this model, from 1982 to 2003, the traffic congestion in the U.S. has continuously become worse in terms of both total delay time and the composition of congestion levels (see Figure 1-3).

3.3.2 Driving Segments

Chapter 2 defines the concept of “driving segments” to characterize all the reasonable driving situations as the combination of vehicle speed, operation patterns and road types (see Figures 2-2 ~ 2-4). Further, the fuel consumption and emissions of 13 light-duty vehicle types under every “driving segment” have been developed into the “Driving Segments” vehicle performance matrices (see Tables A-2-1 ~ A-2-23).

Comparing the definition of “driving segments” with the traffic assumption shown in Figure 1-3, it is obvious that there is no need to differentiate the vehicle speed in the model for traffic changes. Therefore this Chapter transforms the “Driving Segments” vehicle performance matrices into the “Driving Segments” vehicle performance inventories by averaging the fuel consumption and emissions of “driving segments” which have the same operation patterns and road types (see Tables 3-7 ~ 3-9). These "Driving Segments" inventories will be based on mileage instead of time to keep the consistency with the traffic model.

In particular, the fuel consumption and emissions of Hybrid are based on the characteristics of Toyota Prius, and the emissions of EV and FCV are converted from their electricity and hydrogen consumption through life cycle analysis [Mierlo et al., 2003; MaCleese et al., 2002; Heywood et al., 2003; NREL, 2001; Feng et al., 2004].

Table 3-7: "Driving Segments" Vehicle Performance Inventory for Cars and Light Trucks (Automatic Transmission)

		CARS														
TRANSMISSION:		**Two-seater**			**Subcompact**			**Compact**			**Midsize**			**Large**		
AUTOMATIC		FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G
Gasoline (g/mile)	Highway	67.380	81.980	117.163	79.230	106.653	197.004	79.279	112.747	205.802	81.716	115.820	209.209	79.729	113.687	206.299
	Suburban	108.971	105.461	169.744	133.911	167.200	220.848	139.396	184.384	226.352	148.606	189.531	230.240	143.587	185.920	228.352
	Urban	89.331	109.640	184.200	108.509	132.180	241.140	116.436	140.680	248.880	120.502	144.980	253.260	117.782	141.900	250.260
CO2 (g/mile)	Highway	202.110	248.447	352.592	243.551	322.500	578.496	243.769	341.973	625.148	251.276	351.700	635.773	245.160	344.967	626.756
	Suburban	330.305	316.064	506.352	408.442	507.893	670.640	423.306	561.525	687.664	450.281	577.451	699.472	434.742	566.293	693.824
	Urban	270.211	326.160	550.260	332.225	400.580	729.720	356.604	426.560	753.300	369.091	439.520	766.440	360.778	430.280	757.440
HC (g/mile)	Highway	0.180	0.160	0.441	0.128	0.727	3.328	0.120	0.653	1.095	0.116	0.633	1.073	0.116	0.647	1.086
	Suburban	0.197	0.432	1.360	0.537	0.869	1.040	0.762	0.811	1.072	0.923	0.784	1.072	0.923	0.800	1.072
	Urban	0.276	0.940	1.980	0.255	0.760	1.320	0.269	0.780	1.380	0.269	0.760	1.380	0.269	0.760	1.380
NOx (g/mile)	Highway	0.176	0.180	0.377	0.195	0.613	2.198	0.188	0.587	0.951	0.184	0.580	0.949	0.188	0.580	0.947
	Suburban	0.227	0.427	0.912	0.523	0.811	0.688	0.669	0.800	0.720	0.798	0.811	0.736	0.789	0.805	0.720
	Urban	0.320	0.700	1.200	0.313	0.520	0.420	0.342	0.560	0.600	0.349	0.620	0.600	0.342	0.580	0.600
CO (g/mile)	Highway	3.428	2.613	4.991	0.439	2.880	12.534	0.413	2.647	4.406	0.401	2.520	4.335	0.405	2.567	4.374
	Suburban	3.513	5.259	8.816	2.123	3.589	5.024	2.996	3.408	5.056	3.631	3.339	5.024	3.652	3.392	4.976
	Urban	3.018	6.200	7.980	1.215	3.340	6.540	1.280	3.520	6.780	1.265	3.620	6.780	1.280	3.520	6.720
		LIGHT TRUCKS														
TRANSMISSION:		**Small Pickup**			**Large Pickup**			**Small Van**			**Large Van**			**SUV**		
AUTOMATIC		FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G
Gasoline (g/mile)	Highway	111.791	140.473	267.272	136.973	180.393	273.328	153.169	198.453	280.262	126.341	219.540	288.422	137.093	171.027	331.941
	Suburban	200.571	234.533	349.536	243.309	237.771	366.048	262.055	230.517	372.400	267.741	229.056	373.056	230.182	278.155	407.280
	Urban	160.895	209.280	403.140	194.655	226.600	421.920	204.713	232.000	430.140	205.709	232.760	433.020	190.022	238.920	474.960
CO2 (g/mile)	Highway	342.570	419.347	792.548	419.880	549.907	826.314	468.559	604.260	838.271	386.539	666.727	865.391	419.888	514.560	985.798
	Suburban	580.559	703.797	1055.376	739.638	716.837	1107.040	790.327	696.443	1127.328	808.442	691.328	1129.072	689.235	824.016	1229.280
	Urban	488.829	629.820	1214.280	592.044	682.560	1271.640	622.502	699.000	1297.500	623.949	701.340	1305.420	578.262	718.940	1428.360
HC (g/mile)	Highway	0.266	1.273	1.856	0.308	0.440	1.331	0.315	0.400	1.689	0.281	0.440	1.688	0.394	1.780	3.186
	Suburban	1.696	1.659	3.056	0.561	1.488	3.040	0.795	1.365	2.944	0.783	1.381	3.024	2.311	2.603	3.792
	Urban	0.785	1.900	4.080	0.771	1.960	4.200	0.778	1.960	4.140	0.778	1.960	4.320	0.924	2.380	5.160
NOx (g/mile)	Highway	0.671	2.087	2.846	0.806	0.900	2.246	0.806	0.780	2.329	0.679	0.680	2.355	1.080	3.020	4.226
	Suburban	2.167	3.536	4.096	1.125	3.051	4.144	1.227	2.832	3.984	1.197	2.827	3.952	3.427	4.192	4.880
	Urban	2.051	2.800	4.440	1.949	3.080	4.620	1.905	3.140	4.740	1.811	3.140	4.740	2.087	3.160	5.640
CO (g/mile)	Highway	1.151	6.727	17.318	1.350	3.687	8.685	2.164	4.627	13.995	1.725	6.280	12.804	1.425	5.193	18.849
	Suburban	21.385	9.803	9.472	6.368	8.187	8.976	10.436	7.104	8.768	10.109	7.515	8.848	9.265	17.227	10.880
	Urban	3.600	6.900	11.340	4.269	7.100	11.520	4.575	7.180	11.580	5.629	7.220	11.820	3.651	7.400	13.920

* Note: FF = Free Flow, SU/SD = Speed Up / Slow Down, S-G = Stop-and-Go; Suburban = Artery, Urban = Side-Street (same with Table 3-10 and 3-11).

Table 3-8: "Driving Segments" Vehicle Performance Inventory for Cars and Light Trucks (Manual Transmission)

CARS

TRANSMISSION: MANUAL		Two-seater FF	Two-seater SU/SD	Two-seater S-G	Subcompact FF	Subcompact SU/SD	Subcompact S-G	Compact FF	Compact SU/SD	Compact S-G	Midsize FF	Midsize SU/SD	Midsize S-G	Large FF	Large SU/SD	Large S-G
Gasoline (g/mile)	Highway	73.579	82.420	153.096	85.631	100.293	185.222	89.471	105.693	188.184	92.456	109.560	191.663	90.049	106.727	189.486
	Suburban	104.241	131.403	157.232	124.919	142.635	207.008	140.191	157.376	212.000	144.407	161.771	217.200	141.683	159.168	213.520
	Urban	80.153	91.660	182.640	97.767	115.240	242.700	105.716	122.400	249.300	110.095	125.780	252.540	107.025	123.500	250.440
CO2 (g/mile)	Highway	223.939	247.473	461.211	263.175	303.593	539.964	275.179	320.580	571.511	284.363	332.260	582.441	276.934	323.687	575.563
	Suburban	316.350	393.424	473.280	380.995	432.827	627.904	424.373	478.459	643.600	437.267	492.075	659.504	428.845	484.059	648.256
	Urban	243.200	275.300	547.800	299.025	348.940	734.280	323.469	370.920	754.020	336.982	381.200	763.920	327.535	374.260	757.500
HC (g/mile)	Highway	0.158	0.220	0.495	0.135	0.647	3.561	0.128	0.607	0.979	0.128	0.647	0.968	0.124	0.620	0.977
	Suburban	0.197	0.507	1.312	0.486	0.763	1.040	0.902	0.747	1.040	0.909	0.757	1.072	0.911	0.747	1.072
	Urban	0.298	0.860	1.920	0.247	0.640	1.440	0.255	0.660	1.440	0.262	0.700	1.500	0.255	0.660	1.500
NOx (g/mile)	Highway	0.221	0.247	0.493	0.210	0.533	2.331	0.210	0.547	0.844	0.221	0.573	0.846	0.210	0.560	0.844
	Suburban	0.273	0.571	0.880	0.477	0.693	0.608	0.777	0.704	0.640	0.787	0.720	0.656	0.786	0.704	0.656
	Urban	0.371	0.640	0.960	0.291	0.360	0.480	0.320	0.420	0.540	0.320	0.460	0.600	0.320	0.440	0.600
CO (g/mile)	Highway	1.785	4.000	6.338	0.491	2.600	13.464	0.431	2.480	4.121	0.443	2.573	4.011	0.428	2.520	4.089
	Suburban	3.066	6.837	5.376	1.977	3.312	5.136	3.629	3.227	4.928	3.660	3.195	4.960	3.677	3.211	4.944
	Urban	2.109	3.280	6.840	1.251	3.000	6.900	1.295	3.160	6.780	1.287	3.220	6.840	1.280	3.200	6.840

LIGHT TRUCKS

TRANSMISSION: MANUAL		Small Pickup FF	Small Pickup SU/SD	Small Pickup S-G	Large Pickup FF	Large Pickup SU/SD	Large Pickup S-G	Small Van FF	Small Van SU/SD	Small Van S-G	Large Van FF	Large Van SU/SD	Large Van S-G	SUV FF	SUV SU/SD	SUV S-G
Gasoline (g/mile)	Highway	118.549	145.947	227.882	159.450	192.953	285.954	178.823	228.413	265.723	151.751	213.807	260.004	139.448	156.267	253.461
	Suburban	209.943	195.541	313.776	269.337	189.621	320.928	271.873	184.384	323.008	262.385	183.088	323.104	204.112	228.528	373.776
	Urban	163.935	181.640	395.700	187.193	197.620	409.980	200.538	200.060	414.720	204.524	199.840	416.400	173.862	209.720	466.380
CO2 (g/mile)	Highway	363.173	438.120	686.608	486.930	587.393	854.265	544.781	590.553	719.505	462.071	649.987	785.211	427.031	475.040	759.422
	Suburban	615.599	587.707	947.216	814.921	569.936	970.544	714.356	553.259	977.264	796.299	551.093	977.376	615.481	680.528	1118.576
	Urban	496.385	547.160	1191.120	563.309	596.000	1235.460	604.575	603.460	1250.040	616.873	602.760	1254.720	516.764	625.800	1392.240
HC (g/mile)	Highway	0.281	1.433	1.678	0.349	0.473	1.954	0.371	2.293	3.124	0.338	0.447	1.624	0.428	0.987	2.839
	Suburban	1.659	1.547	2.880	0.605	1.413	2.752	2.674	1.541	2.704	0.550	1.552	2.720	1.507	2.565	4.976
	Urban	0.858	1.780	4.200	0.858	1.860	4.140	0.836	1.860	4.080	0.844	1.860	4.080	1.549	2.960	7.080
NOx (g/mile)	Highway	0.690	1.973	2.372	0.791	0.873	1.926	0.799	0.993	2.089	0.660	0.707	2.034	1.013	1.793	3.446
	Suburban	2.070	2.683	3.344	1.038	2.080	3.248	1.434	2.176	3.136	1.004	2.336	3.168	2.651	3.547	5.184
	Urban	1.913	2.200	4.260	1.775	2.360	4.500	1.665	2.360	4.380	1.644	2.400	4.440	2.618	3.220	6.360
CO (g/mile)	Highway	1.271	5.253	7.646	2.801	4.413	14.507	3.953	68.627	58.442	3.503	5.627	8.203	1.436	2.847	9.904
	Suburban	17.644	7.211	8.416	9.479	7.211	7.728	74.479	7.259	7.568	7.762	6.085	7.680	6.510	11.083	13.424
	Urban	4.582	5.300	11.280	7.702	5.560	11.100	7.702	5.520	11.100	7.665	5.560	11.340	9.796	8.200	17.280

Table 3-9: "Driving Segments" Vehicle Performance Inventory for New Tech

						NEW TECH				
TRANSMISSION:		**Hybrid**			**EV**			**FCV**		
AUTOMATIC = MANUAL		FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G
Gasoline (g/mile)	Highway	72.323	75.353	101.113	26.676	26.379	39.594	39.516	47.070	71.079
	Suburban	88.893	95.488	115.584	33.187	35.909	32.632	54.997	64.670	133.775
	Urban	78.553	83.920	97.260	25.084	25.265	37.698	55.530	70.326	174.977
CO2 (g/mile)	Highway	221.756	226.993	304.508	227.123	224.587	337.095	224.430	267.087	403.350
	Suburban	268.086	287.520	346.016	282.541	305.733	277.808	312.062	366.992	758.544
	Urban	238.851	252.060	285.900	213.556	215.080	321.000	315.135	399.020	991.680
HC (g/mile)	Highway	0.285	1.007	1.468	0.045	0.047	0.054	0.229	0.280	0.433
	Suburban	1.167	1.296	2.272	0.059	0.053	0.032	0.328	0.405	0.816
	Urban	0.676	1.400	3.240	0.036	0.020	0.000	0.349	0.440	0.960
NOx (g/mile)	Highway	0.229	0.493	0.591	0.484	0.487	0.720	0.686	0.813	1.224
	Suburban	0.582	0.683	0.464	0.598	0.651	0.624	0.938	1.120	2.336
	Urban	0.400	0.400	0.180	0.458	0.480	0.660	0.960	1.240	3.000
CO (g/mile)	Highway	0.443	1.647	2.078	2.666	2.647	3.969	0.278	0.340	0.495
	Suburban	1.823	2.171	2.640	3.326	3.589	3.296	0.375	0.448	0.960
	Urban	1.076	1.780	3.060	2.509	2.540	3.840	0.371	0.520	1.260

3.3.3 Vehicle Performance Assessment

Combining the above traffic model with the "Driving Segments" vehicle performance inventories, the "On-road" fuel consumption and emissions of 13 light-duty vehicle types as well as the impacts of worsening traffic can be investigated (see Figures 3-23 ~ 3-32).

For simplicity, the following assumptions have been made:

- The assessment for vehicle performance ranges from 1982 to 2003. During this period, the improvement of vehicle technology has been ignored to emphasize the impacts of worsening traffic on vehicle emissions and fuel consumption.
- The relationship between the operation patterns of driving segments and the congestion levels of traffic model: Free Flow = Uncongested + Moderate; Speed Up/Slow Down = Heavy + Severe; Stop-and-Go = Extreme.
- The composition data of congestion levels are based on mileage, and the data between 1982 and 2003 are linearly interpolated (see Figure 3-22).
- The percentages for Highway, Suburban Road and Urban Street in the annual

mileage are fixed as 30%, 20% and 50% respectively, which can be changed in future sensitivity analysis.

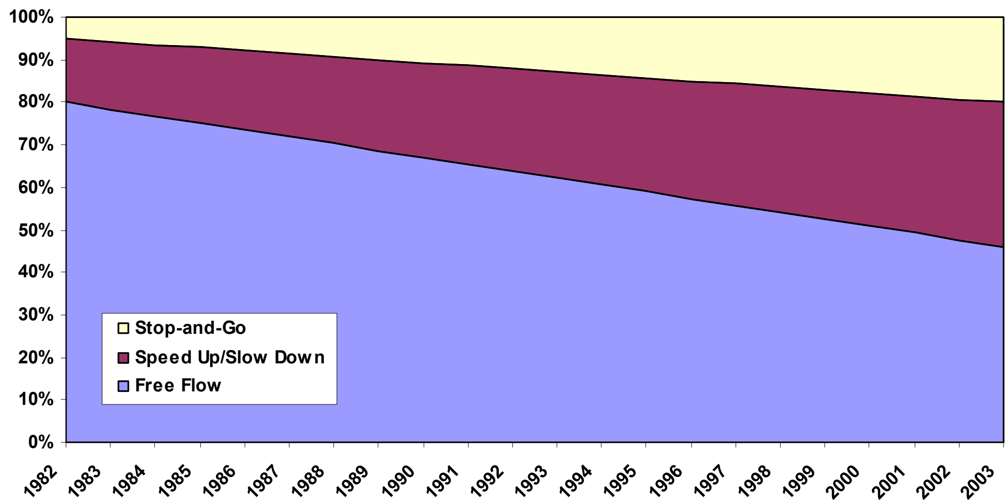

Figure 3-22: Percentage Composition of Congestion Levels (1982-2003)

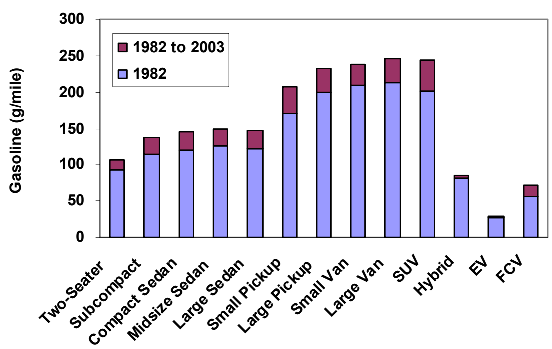

Figure 3-23: Fuel Consumption Change (Automatic)

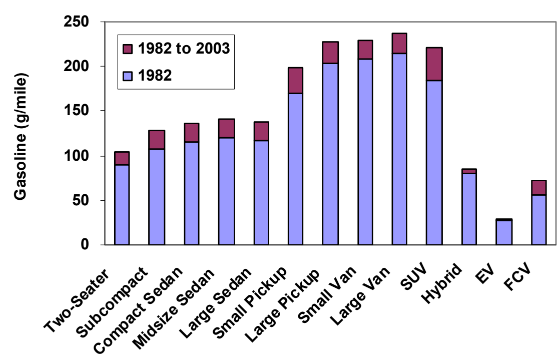

Figure 3-24: Fuel Consumption Change (Manual)

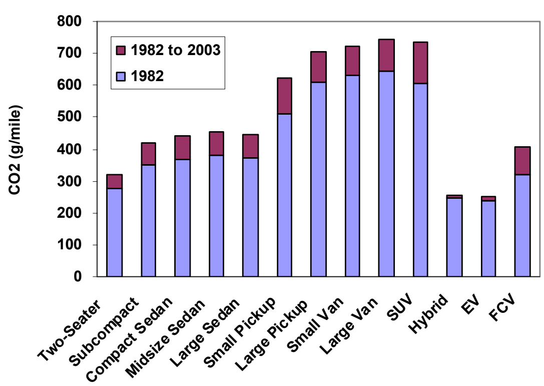

Figure 3-25: CO_2 Emission Change (Automatic)

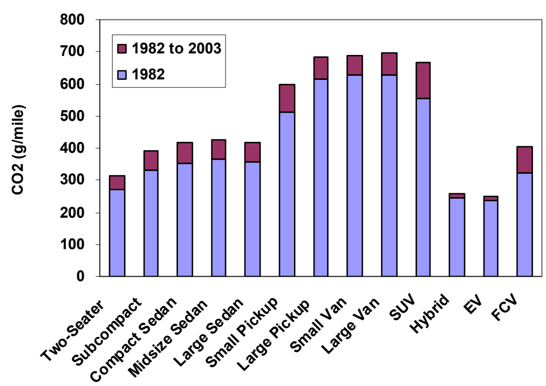

Figure 3-26: CO_2 Emission Change (Manual)

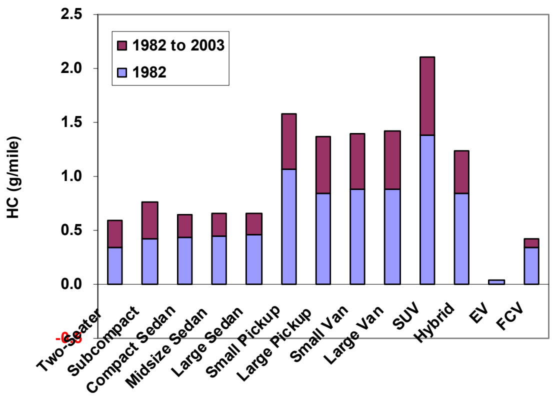

Figure 3-27: HC Emission Change (Automatic)

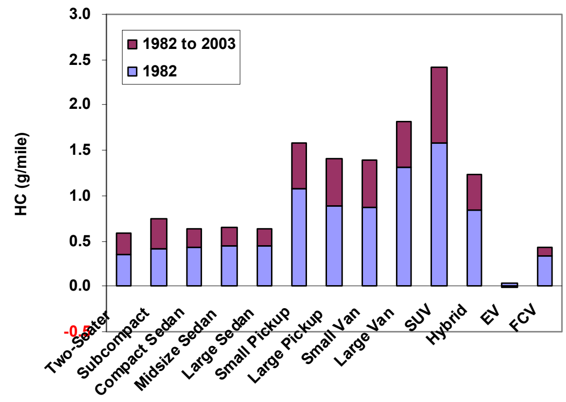

Figure 3-28: HC Emission Change (Manual)

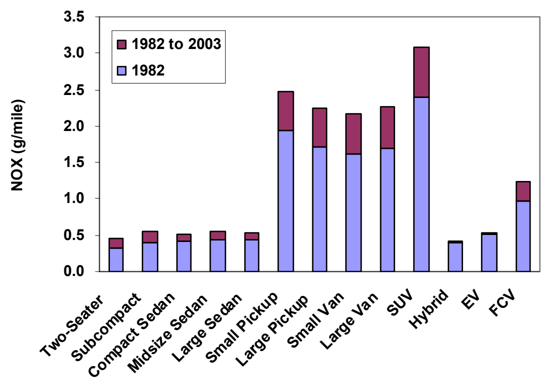

Figure 3-29: NO_X Emission Change (Automatic)

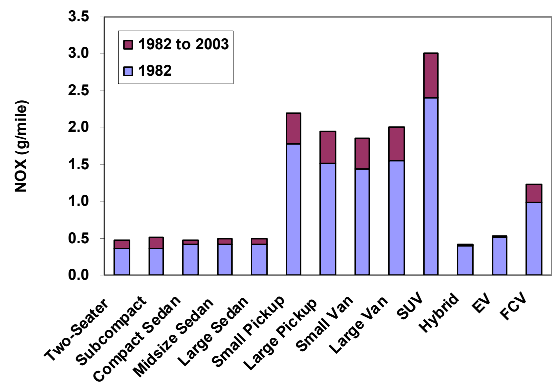

Figure 3-30: NO_X Emission Change (Manual)

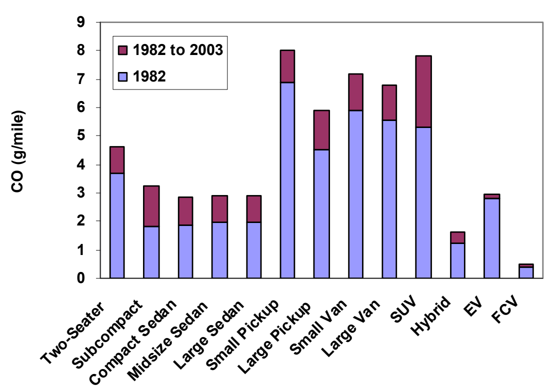

Figure 3-31: CO Emission Change (Automatic)

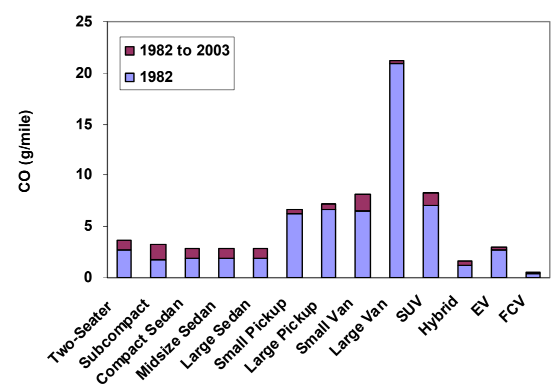

Figure 3-32: CO Emission Change (Manual)

From the above Figures 3-23 ~ 3-32, two major conclusions can be drawn:

- In terms of the change of fuel consumption and CO_2 emission, worsening traffic has the largest impacts on SUV while has the smallest impacts on Hybrid and EV.
- For most light-duty vehicle types, worsening traffic has more impacts on automatic transmissions than manual transmissions (for conventional light-duty vehicles).

3.3.4 "On-road" Fuel Economy

From Figures 3-23 and 3-24, it is straightforward to get the annual change of "On-road" fuel economy for different light-duty vehicle types (see Figures 3-33 and 3-34). Further, the difference between the "On-road" fuel economy and the "FEG" fuel economy can also be visualized (see Figures 3-35 and 3-36) with the following assumptions:

- Only 11 light-duty vehicle types are compared because of the lack of "FEG" fuel economy for EV and FCV.
- Toyota Prius is the prototype to develop the "On-road" and "FEG" fuel economy for Hybrid.
- The "On-road" fuel economy is calculated by averaging the 2003 data for automatic transmission and manual transmission (see Figures 3-33 and 3-34). And the "FEG" fuel economy is calculated by averaging the highest and the lowest data of each vehicle type in the Fuel Economy Guide [DOE and EPA, 2005].
- The "On-road" fuel economy here is based on the traffic assumption for all kinds of commutes (see Figure 3-22) and therefore is more representative than the previous "On-road" fuel economy (see Figure 3-21), which is only based on a specific work commute (see Figures 3-1, 3-2 and Table 3-2).

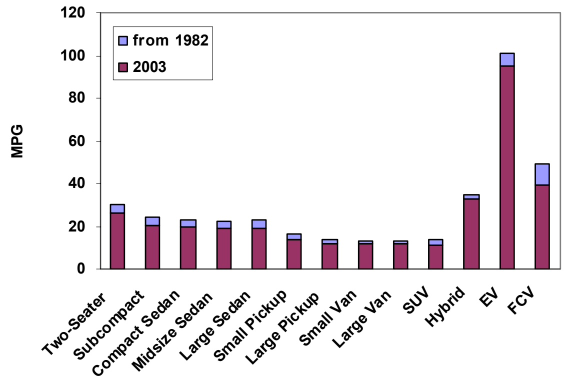

Figure 3-33: Fuel Economy Change (Automatic)

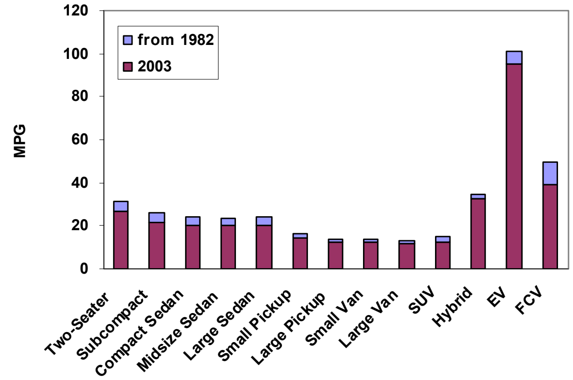

Figure 3-34: Fuel Economy Change (Manual)

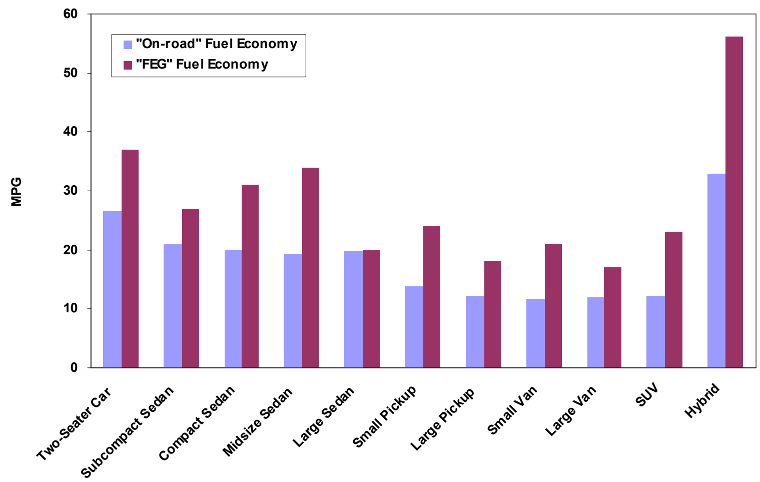

Figure 3-35: Value Comparison between "On-road" and "FEG" Fuel Economy

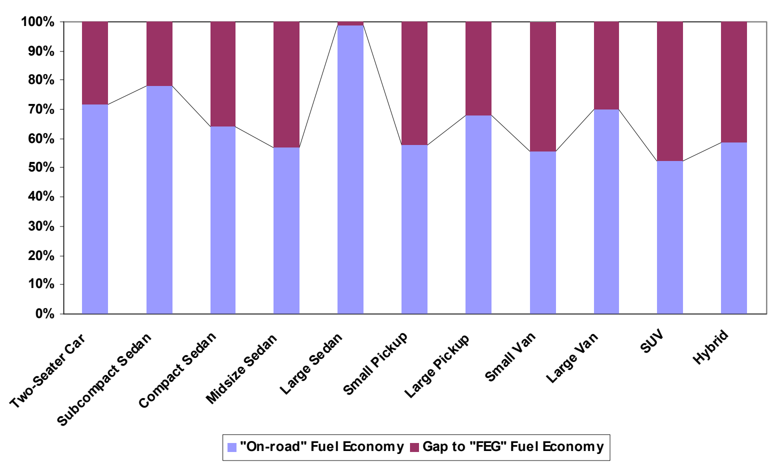

Figure 3-36: Percentage Comparison between "On-road" and "FEG" Fuel Economy

From the above Figures 3-33 ~ 3-36, several conclusions are made as below:

- In terms of the change of fuel economy, worsening traffic has the largest impacts on FCV while has the smallest impacts on Small Van and Large Van (see Figures 3-33 and 3-34).
- From 1982 to 2003, the drop of fuel economy for light-duty vehicles caused by worsening traffic ranges from 2 ~ 10 MPG (see Figures 3-33 and 3-34).
- The “On-road” fuel economy for light-duty vehicles are normally 5 ~ 10 MPG lower (see Figure 3-35) and only equivalent to 60% ~ 70% (see Figure 3-36) of the “FEG” fuel economy from the U.S. EPA.

3.4 Summary

By method of the “Velocity-Acceleration” and “Driving Segments” vehicle performance matrices, this Chapter quantitatively estimates the impacts of worsening traffic on individual vehicle’s fuel consumption and emissions.

The important conclusions in this Chapter are summarized as below:

- The amount of fuel consumption and emissions from light-duty vehicles are underestimated because of the characteristics of the existing driving cycles.
- The “On-road” fuel economy for light-duty vehicles are normally 5 ~ 10 MPG lower and only equivalent to 60% ~ 70% of EPA’s fuel economy developed in the Fuel Economy Guide.
- In terms of the change of fuel consumption and CO_2 emission, worsening traffic has the largest impacts on SUV while has the smallest impacts on Hybrid and EV.

- In terms of the change of fuel economy, worsening traffic has the largest impacts on FCV while has the smallest impacts on Small and Large Vans.

CHAPTER 4: IMPACTS OF WORSENING TRAFFIC ON THE U.S. LIGHT-DUTY VEHICLE FLEET

4.1 Introduction

This Chapter uses "Driving Segments" vehicle performance matrices to assess energy and environmental impacts of worsening traffic on the U.S. light-duty vehicle fleet from 1982 to 2030. Further, this Chapter investigates the feasibility and effectiveness of offsetting these impacts over the next 27 years (2004-2030) by the methods of altering vehicle choice, developing vehicle technology, and changing driving behavior.

4.2 Methodology

Fuel consumption and emissions of the U.S. light-duty vehicle fleet are the quantitative indices for energy and environmental impacts of worsening traffic. However, the fleet fuel consumption and emissions are not only determined by traffic congestion but also by other major factors including fleet population, vehicle technology and driving behavior, which obviously add much more difficulty to quantify the impacts of worsening traffic on the light-duty vehicle fleet instead of on individual vehicles (see Chapter 3). Based on the historical data and reasonable assumptions, this thesis establishes four models for fleet growth and vehicle technology, driving behavior as well as traffic congestion changes respectively. Integrating these models together, fuel consumption and emissions of the U.S. light-duty vehicle fleet can be calculated.

With the fleet fuel consumption and emissions, this thesis defines different scenarios to distinguish the impacts of worsening traffic from those of other major factors. Moreover, with sensitivity analysis for the above models, this thesis is also able to explore how to offset the impacts of worsening traffic by influencing other factors, that is, altering vehicle choice (and then vehicle population), developing vehicle technology, as well as changing driving behavior.

4.3 Modeling

This section describes the process to establish general models for four major factors on the fleet fuel consumption and emissions: vehicle population, vehicle technology, driving behavior and traffic congestion. For each model, its main structure and underlying assumptions are discussed here in detail. These assumptions define the Reference Case and are subject to sensitivity analysis.

4.3.1 Fleet Population Model

Combining vehicle new sales and sale shares with the survival rates, this model calculates the annual in-use amount of each vehicle type with a specific model year. In this model, 13 light-duty vehicle types (see Table 2-3) in the U.S. market are considered and their model year ranges from 1976 to 2030. These vehicle types have been divided into three categories: passenger cars, light trucks and new technologies (Hybrid, EV and FCV).

New Sales and Sale Shares

The historical data (1976-2003) for annual new sales and sale shares of each light-duty vehicle type can be found in the Transportation Energy Data Book, Ed 24 [ORNL, 2005], and the projections for data after 2003 are based on the following assumptions:

- The change rate of total light-duty vehicle sales is the same as that of the U.S. population, i.e., 0.8% / year (the medium projection of the U.S. Bureau of Census).
- The penetration of new technologies is linear and begins in 2004: the changes of sale shares for Hybrid, EV and FCV are 1% / year (the medium projection of the MIT LFEE) [Heywood et al., 2003], 0.2% / year and 0.1% / year respectively.
- In addition to new technologies, the sale shares of other vehicle types are derived from the historical data by linear extrapolation. There are two reasons for this thesis to adopt the linear extrapolation: one is for simplicity; and the other lies in that the historical data do not produce sufficient insight to use another method, such as polynomial extrapolation. And two measures have been made to avoid common extrapolation errors: first, the slope of linear extrapolation is taken as the average change rate from 1976-2003 instead of the change rate from 2002-2003 (Linear Extrapolation 2 is more credible than Linear Extrapolation 1, see Figure 4-1); second, if the extrapolation results become negative, the sale shares should level off to the minimal positive value (Linear Extrapolation 4 is more reasonable than Linear Extrapolation 3, see Figure 4-2).

With the estimated total sales and sale shares, the new sales of each vehicle type after 2003 can be calculated. Finally, the annual new sales and sale shares for all the light-duty vehicle types from 1976 to 2030 are summarized in Tables A-4-1 ~ A-4-4 (see the Appendix).

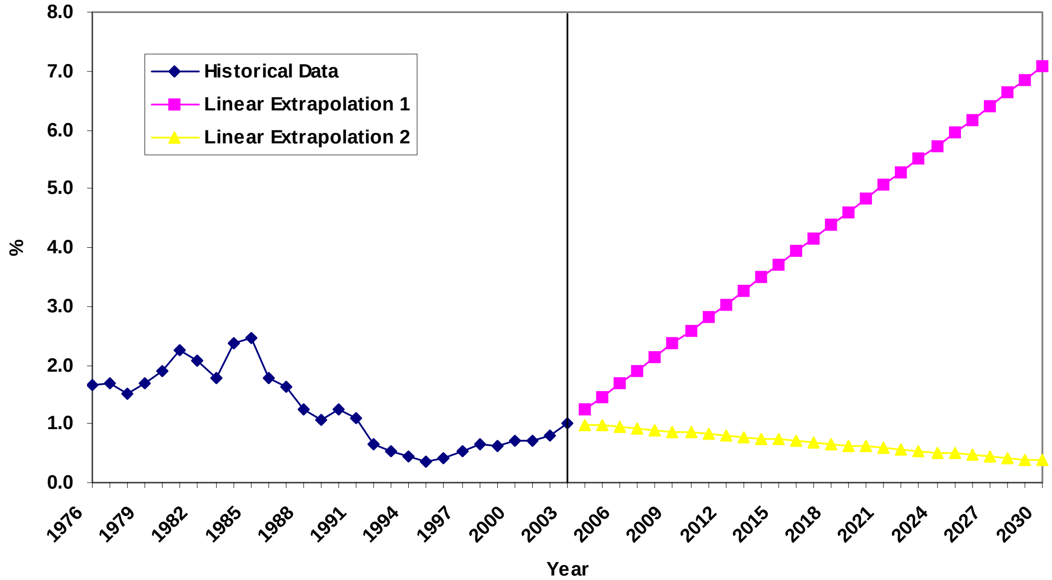

Figure 4-1: Linear Extrapolation and Sale Shares of Two-seater Cars

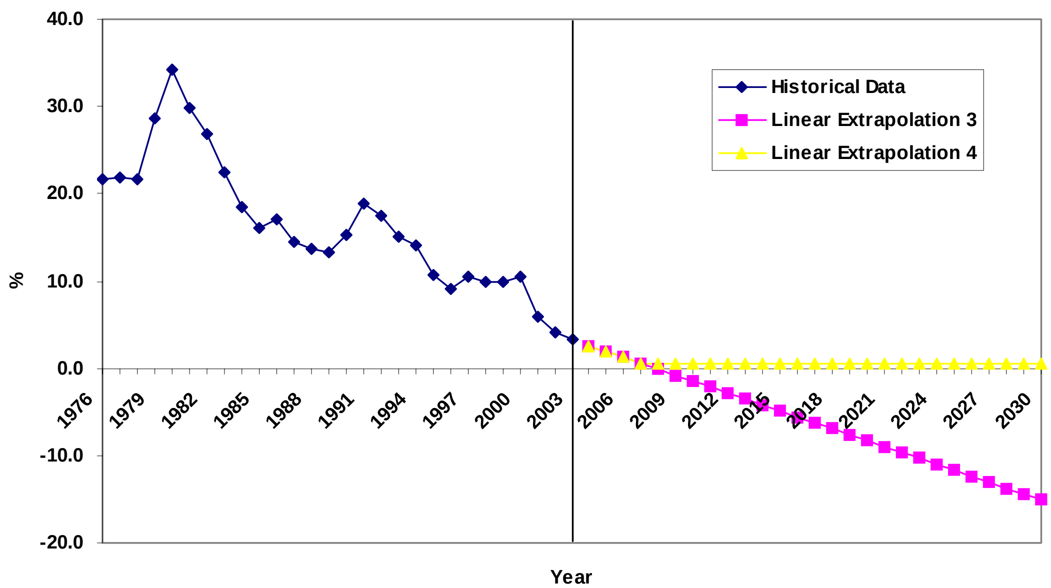

Figure 4-2: Linear Extrapolation and Sale Shares of Subcompact Cars

Survival Rates

Survival rate is defined as the percentage of light-duty vehicles which will be in use at the end of the year, and it should vary with vehicle type, vehicle model as well as vehicle age. For simplicity, the following assumptions have been made:

- The survival rates of new vehicle technologies are the same as those of passenger cars, which are different from the survival rates of light trucks.
- The road life (in USA) for passenger cars and new technologies is supposed as 10 years, and the road life (in USA) for light trucks is supposed as 16 years [ORNL, 2005].
- Survival rates are adjusted every 10 model years.
- The survival rates for model year 1970, 1980 and 1990 can be found in the Transportation Energy Data Book, Ed 24 [ORNL, 2005].
- The survival rates for model year 1975 and before can be developed from the 1970 values.
- The survival rates for model year 2000 can be linearly extrapolated from the previous values.
- The survival rates for model year after 2000 keep constant because of insufficient evidence on the potential for increasing vehicle durability [Bassene, 2001].

Based on the above assumptions, the survival rates for passenger cars and new technologies are summarized in Table A-4-5, and the survival rates for light trucks are summarized in Table A-4-6 (see the Appendix).

Fleet Stock Inventory

For each vehicle type, its new sales in any year between 1976 and 2030 are taken as the initial amount of this year's model. Multiplying the initial amount by relevant survival rates, the annual in-use amount of this model in subsequent years can be calculated. Moreover, the initial amount of the models before 1976, which is negligible after 10 ~ 16 years, can be approximately developed from the total registered number of light-duty vehicles [ORNL, 2005] and the sale shares in 1976. Adding the annual in-use amount of all models together, the population inventory for each vehicle type is generated (see Table A-4-7 in the Appendix, the example of Two-seater Cars). Further, the stock (total on-road vehicles) and composition of the U.S. light-duty vehicle fleet can be obtained by aggregating all the inventories for 13 vehicle types (see Figures 4-3 ~ 4-4 and Figures A-4-1 ~ A-4-4). In this thesis, all the fleet data are represented with three versions based on different vehicle classification (see Table 4-1), among which Version 2 is given in the Chapter (such as Figures 4-3 ~ 4-4), while Version 1 and Version 3 are collected in the Appendix (such as Figures A-4-1 ~ A-4-4).

From the fleet population model and the above results in the Reference Case, several conclusions can be drawn as below:

- Among the 13 light-duty vehicle types, there will be a distinct growth in the population of SUV and Hybrid from 2004 to 2030: the number of SUV will begin to exceed other vehicle types in 2007, and the number of Hybrid will rank the second from 2027; On the contrary, the population of Subcompact Cars will fall considerably (see Figures A-4-1 and A-4-2).
- Different from SUV, the population of other light trucks (Pickup and Van) will not change a lot during the period of 2004-2030 (see Figures 4-3 and 4-4).

- The total number of passenger cars will increase a little and then begin to decrease around 2013, since which the total number of light trucks will exceed passenger cars because of the strong growth of SUV (see Figures A-4-3 and A-4-4).

Finally, it should be noted that these conclusions in the Reference Case describe the baseline and are subject to comparison with other scenarios through sensitivity analysis.

Table 4-1: Three Versions for Vehicle Classification

Version 1	Version 2	Version 3
Two-seater	Passenger Car	Passenger Car
Subcompact		
Compact		
Midsize		
Large		
Small pickup	Pickup	Light Truck
Large pickup		
Small van	Van	
Large van		
SUV	SUV	
Hybrid	New Tech	New Tech
EV		
FCV		

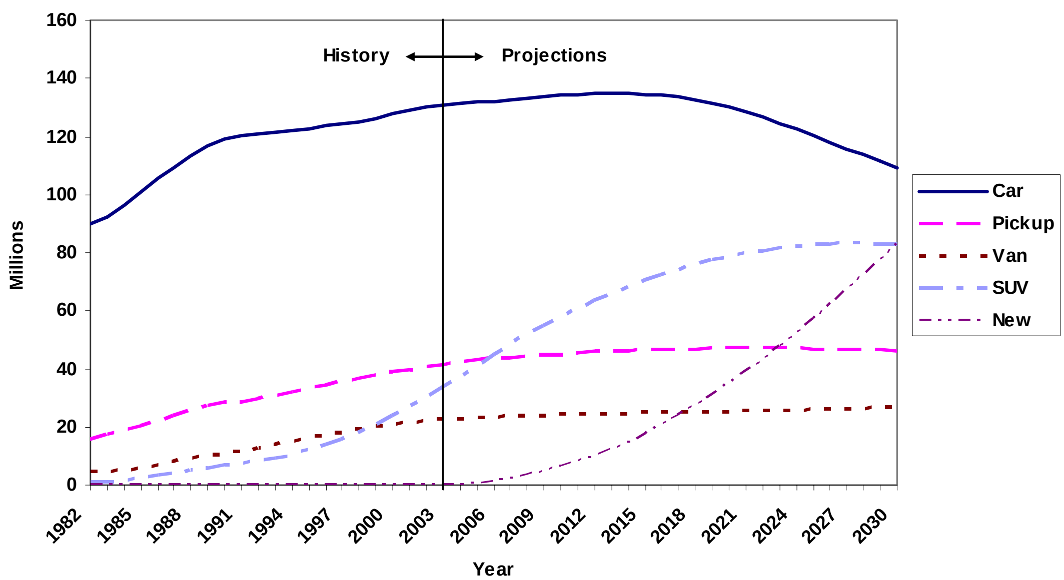

Figure 4-3: The U.S. Light-Duty Vehicle Fleet Stock (Version 2)

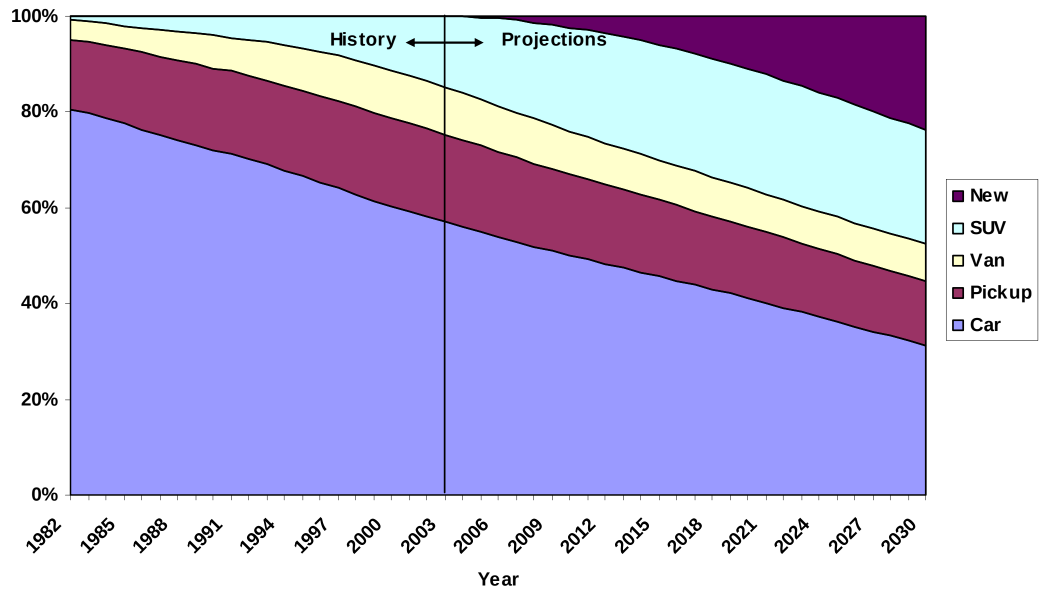

Figure 4-4: Population Composition of the U.S. Light-Duty Vehicle Fleet (Version 2)

4.3.2 Vehicle Technology Model

From the view of vehicle technology, the fuel consumption and emissions of each vehicle type will change with vehicle model and vehicle age. This model calculates baseline characteristics inventories for recent model (vehicle model = MY 2000) and new vehicle (vehicle age = 0 year) from the "Driving Segments" vehicle performance matrices, as well as deals with the impacts of vehicle model and vehicle age. In addition, because the "Driving Segments" matrices consider the difference between automatic transmission and manual transmission for conventional light-duty vehicles, the effect of automatic/manual ratio on the baseline characteristics inventory will also be considered.

Baseline Characteristics Inventory

Developed in Chapter 2, the "Driving Segments" vehicle performance matrices (see Tables A-2-1 ~ A-2-23) give the fuel consumption and emissions of each vehicle type under a specific speed and operation pattern (Free Flow, Speed Up/Slow Down or Stop-and-Go) as well as on some type of road (Highway, Suburban or Urban). Approximately, this thesis assumes all these data in "Driving Segments" matrices are tested from recent model (MY 2000) and new vehicles (0-year-old).

Further, in order to meet the requirements of possible traffic model, this thesis transforms the "Driving Segments" matrices into baseline characteristics inventories by averagely merging all the "driving segments" which have the same operation pattern and road type. In other words, baseline characteristics inventories will not differentiate the vehicle speed for calculating vehicle fuel consumption and emissions (see Tables 4-2 ~ 4-4, the same as the "Driving Segments" inventories in Chapter 3).

Specifically, Table 4-2 summarizes the fuel consumption and emissions of passenger cars and light trucks with automatic transmission (MY 2000 and 0-year-old), Table 4-3 summarizes the fuel consumption and emissions of passenger cars and light trucks with manual transmission (MY 2000 and 0-year-old), and Table 4-4 summarizes the fuel consumption and emissions of Hybrid, EV and FCV, which have no difference between automatic and manual transmissions. As described above, each value in those tables is identified by vehicle type (see Table 2-3), operation pattern (Free Flow, Speed Up/Slow Down or Stop-and-Go) and road type (Highway, Suburban or Urban). In particular, the fuel consumption and emissions of Hybrid are based on the characteristics of Toyota Prius, and the emissions of EV and FCV are converted from their electricity and hydrogen consumption through life cycle analysis [Mierlo et al., 2003; MaCleese et al., 2002; Heywood et al., 2003; NREL, 2001; Feng et al., 2004].

Table 4-2: Baseline Characteristics Inventory (cars and light trucks with automatic transmission, MY 2000 & 0-year-old)

CARS

TRANSMISSION:		Two-seater			Subcompact			Compact			Midsize			Large		
AUTOMATIC		FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G
Gasoline	Highway	67.380	81.980	117.163	79.230	106.653	197.004	79.279	112.747	205.802	81.716	115.820	209.209	79.729	113.687	206.299
(g/mile)	Suburban	108.971	105.461	169.744	133.911	167.200	220.848	139.396	184.384	226.352	148.606	189.531	230.240	143.587	185.920	228.352
	Urban	89.331	109.640	184.200	108.509	132.180	241.140	116.436	140.680	248.880	120.502	144.980	253.260	117.782	141.900	250.260
CO2 (g/mile)	Highway	202.110	248.447	352.592	243.551	322.500	578.496	243.769	341.973	625.148	251.276	351.700	635.773	245.160	344.967	626.756
	Suburban	330.305	316.064	506.352	408.442	507.893	670.640	423.306	561.525	687.664	450.281	577.451	699.472	434.742	566.293	693.824
	Urban	270.211	326.160	550.260	332.225	400.580	729.720	356.604	426.560	753.300	369.091	439.520	766.440	360.778	430.280	757.440
HC (g/mile)	Highway	0.180	0.160	0.441	0.128	0.727	3.328	0.120	0.653	1.095	0.116	0.633	1.073	0.116	0.647	1.086
	Suburban	0.197	0.432	1.360	0.537	0.869	1.040	0.762	0.811	1.072	0.923	0.784	1.072	0.923	0.800	1.072
	Urban	0.276	0.940	1.980	0.255	0.760	1.320	0.269	0.780	1.380	0.269	0.760	1.380	0.269	0.760	1.380
NOx (g/mile)	Highway	0.176	0.180	0.377	0.195	0.613	2.198	0.188	0.587	0.951	0.184	0.580	0.949	0.188	0.580	0.947
	Suburban	0.227	0.427	0.912	0.523	0.811	0.688	0.669	0.800	0.720	0.798	0.811	0.736	0.789	0.805	0.720
	Urban	0.320	0.700	1.200	0.313	0.520	0.420	0.342	0.560	0.600	0.349	0.620	0.600	0.342	0.580	0.600
CO (g/mile)	Highway	3.428	2.613	4.991	0.439	2.880	12.534	0.413	2.647	4.406	0.401	2.520	4.335	0.405	2.567	4.374
	Suburban	3.513	5.259	8.816	2.123	3.589	5.024	2.996	3.408	5.056	3.631	3.339	5.024	3.652	3.392	4.976
	Urban	3.018	6.200	7.980	1.215	3.340	6.540	1.280	3.520	6.780	1.265	3.620	6.780	1.280	3.520	6.720

LIGHT TRUCKS

TRANSMISSION:		Small Pickup			Large Pickup			Small Van			Large Van			SUV		
AUTOMATIC		FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G
Gasoline	Highway	111.791	140.473	267.272	136.973	180.393	273.328	153.169	198.453	280.262	126.341	219.540	288.422	137.093	171.027	331.941
(g/mile)	Suburban	200.571	234.533	349.536	243.309	237.771	366.048	262.055	230.517	372.400	267.741	229.056	373.056	230.182	278.155	407.280
	Urban	160.895	209.280	403.140	194.655	226.600	421.920	204.713	232.000	430.140	205.709	232.760	433.020	190.022	238.920	474.960
CO2 (g/mile)	Highway	342.570	419.347	792.548	419.880	549.907	826.314	468.559	604.260	838.271	386.539	666.727	865.391	419.888	514.560	985.798
	Suburban	580.559	703.797	1055.376	739.638	716.837	1107.040	790.327	696.443	1127.328	808.442	691.328	1129.072	689.235	824.016	1229.280
	Urban	488.829	629.820	1214.280	592.044	682.560	1271.640	622.502	699.000	1297.500	623.949	701.340	1305.420	578.262	718.940	1428.360
HC (g/mile)	Highway	0.266	1.273	1.856	0.308	0.440	1.331	0.315	0.400	1.689	0.281	0.440	1.688	0.394	1.780	3.186
	Suburban	1.696	1.659	3.056	0.561	1.488	3.040	0.795	1.365	2.944	0.783	1.381	3.024	2.311	2.603	3.792
	Urban	0.785	1.900	4.080	0.771	1.960	4.200	0.778	1.960	4.140	0.778	1.960	4.320	0.924	2.380	5.160
NOx (g/mile)	Highway	0.671	2.087	2.846	0.806	0.900	2.246	0.806	0.780	2.329	0.679	0.680	2.355	1.080	3.020	4.226
	Suburban	2.167	3.536	4.096	1.125	3.051	4.144	1.227	2.832	3.984	1.197	2.827	3.952	3.427	4.192	4.880
	Urban	2.051	2.800	4.440	1.949	3.080	4.620	1.905	3.140	4.740	1.811	3.140	4.740	2.087	3.160	5.640
CO (g/mile)	Highway	1.151	6.727	17.318	1.350	3.687	8.685	2.164	4.627	13.995	1.725	6.280	12.804	1.425	5.193	18.849
	Suburban	21.385	9.803	9.472	6.368	8.187	8.976	10.436	7.104	8.768	10.109	7.515	8.848	9.265	17.227	10.880
	Urban	3.600	6.900	11.340	4.269	7.100	11.520	4.575	7.180	11.580	5.629	7.220	11.820	3.651	7.400	13.920

* Note: FF = Free Flow, SU/SD = Speed Up / Slow Down, S-G = Stop-and-Go.

Table 4-3: Baseline Characteristics Inventory (cars and light trucks with manual transmission, MY 2000 & 0-year-old)

CARS																
TRANSMISSION:		**Two-seater**			**Subcompact**			**Compact**			**Midsize**			**Large**		
MANUAL		FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G
Gasoline	Highway	73.579	82.420	153.096	85.631	100.293	185.222	89.471	105.693	188.184	92.456	109.560	191.663	90.049	106.727	189.486
(g/mile)	Suburban	104.241	131.403	157.232	124.919	142.635	207.008	140.191	157.376	212.000	144.407	161.771	217.200	141.683	159.168	213.520
	Urban	80.153	91.660	182.640	97.767	115.240	242.700	105.716	122.400	249.300	110.095	125.780	252.540	107.025	123.500	250.440
CO2 (g/mile)	Highway	223.939	247.473	461.211	263.175	303.593	539.964	275.179	320.580	571.511	284.363	332.260	582.441	276.934	323.687	575.563
	Suburban	316.350	393.424	473.280	380.995	432.827	627.904	424.373	478.459	643.600	437.267	492.075	659.504	428.845	484.059	648.256
	Urban	243.200	275.300	547.800	299.025	348.940	734.280	323.469	370.920	754.020	336.982	381.200	763.920	327.535	374.260	757.500
HC (g/mile)	Highway	0.158	0.220	0.495	0.135	0.647	3.561	0.128	0.607	0.979	0.128	0.647	0.968	0.124	0.620	0.977
	Suburban	0.197	0.507	1.312	0.486	0.763	1.040	0.902	0.747	1.040	0.909	0.757	1.072	0.911	0.747	1.072
	Urban	0.298	0.860	1.920	0.247	0.640	1.440	0.255	0.660	1.440	0.262	0.700	1.500	0.255	0.660	1.500
NOx (g/mile)	Highway	0.221	0.247	0.493	0.210	0.533	2.331	0.210	0.547	0.844	0.221	0.573	0.846	0.210	0.560	0.844
	Suburban	0.273	0.571	0.880	0.477	0.693	0.608	0.777	0.704	0.640	0.787	0.720	0.656	0.786	0.704	0.656
	Urban	0.371	0.640	0.960	0.291	0.360	0.480	0.320	0.420	0.540	0.320	0.460	0.600	0.320	0.440	0.600
CO (g/mile)	Highway	1.785	4.000	6.338	0.491	2.600	13.464	0.431	2.480	4.121	0.443	2.573	4.011	0.428	2.520	4.089
	Suburban	3.066	6.837	5.376	1.977	3.312	5.136	3.629	3.227	4.928	3.660	3.195	4.960	3.677	3.211	4.944
	Urban	2.109	3.280	6.840	1.251	3.000	6.900	1.295	3.160	6.780	1.287	3.220	6.840	1.280	3.200	6.840

LIGHT TRUCKS																
TRANSMISSION:		**Small Pickup**			**Large Pickup**			**Small Van**			**Large Van**			**SUV**		
MANUAL		FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G
Gasoline	Highway	118.549	145.947	227.882	159.450	192.953	285.954	178.823	228.413	265.723	151.751	213.807	260.004	139.448	156.267	253.461
(g/mile)	Suburban	209.943	195.541	313.776	269.337	189.621	320.928	271.873	184.384	323.008	262.385	183.088	323.104	204.112	228.528	373.776
	Urban	163.935	181.640	395.700	187.193	197.620	409.980	200.538	200.060	414.720	204.524	199.840	416.400	173.862	209.720	466.380
CO2 (g/mile)	Highway	363.173	438.120	686.608	486.930	587.393	854.265	544.781	590.553	719.505	462.071	649.987	785.211	427.031	475.040	759.422
	Suburban	615.599	587.707	947.216	814.921	569.936	970.544	714.356	553.259	977.264	796.299	551.093	977.376	615.481	680.528	1118.576
	Urban	496.385	547.160	1191.120	563.309	596.000	1235.460	604.575	603.460	1250.040	616.873	602.760	1254.720	516.764	625.800	1392.240
HC (g/mile)	Highway	0.281	1.433	1.678	0.349	0.473	1.954	0.371	2.293	3.124	0.338	0.447	1.624	0.428	0.987	2.839
	Suburban	1.659	1.547	2.880	0.605	1.413	2.752	2.674	1.541	2.704	0.550	1.552	2.720	1.507	2.565	4.976
	Urban	0.858	1.780	4.200	0.858	1.860	4.140	0.836	1.860	4.080	0.844	1.860	4.080	1.549	2.960	7.080
NOx (g/mile)	Highway	0.690	1.973	2.372	0.791	0.873	1.926	0.799	0.993	2.089	0.660	0.707	2.034	1.013	1.793	3.446
	Suburban	2.070	2.683	3.344	1.038	2.080	3.248	1.434	2.176	3.136	1.004	2.336	3.168	2.651	3.547	5.184
	Urban	1.913	2.200	4.260	1.775	2.360	4.500	1.665	2.360	4.380	1.644	2.400	4.440	2.618	3.220	6.360
CO (g/mile)	Highway	1.271	5.253	7.646	2.801	4.413	14.507	3.953	68.627	58.442	3.503	5.627	8.203	1.436	2.847	9.904
	Suburban	17.644	7.211	8.416	9.479	7.211	7.728	74.479	7.259	7.568	7.762	6.085	7.680	6.510	11.083	13.424
	Urban	4.582	5.300	11.280	7.702	5.560	11.100	7.702	5.520	11.100	7.665	5.560	11.340	9.796	8.200	17.280

* Note: FF = Free Flow, SU/SD = Speed Up / Slow Down, S-G = Stop-and-Go.

Table 4-4: Baseline Characteristics Inventory (new technologies, automatic = manual)

		NEW TECH								
TRANSMISSION:		Hybrid			EV			FCV		
AUTOMATIC = MANUAL		FF	SU/SD	S-G	FF	SU/SD	S-G	FF	SU/SD	S-G
Gasoline (g/mile)	Highway	72.323	75.353	101.113	26.676	26.379	39.594	39.516	47.070	71.079
	Suburban	88.893	95.488	115.584	33.187	35.909	32.632	54.997	64.670	133.775
	Urban	78.553	83.920	97.260	25.084	25.265	37.698	55.530	70.326	174.977
CO2 (g/mile)	Highway	221.756	226.993	304.508	227.123	224.587	337.095	224.430	267.087	403.350
	Suburban	268.086	287.520	346.016	282.541	305.733	277.808	312.062	366.992	758.544
	Urban	238.851	252.060	285.900	213.556	215.080	321.000	315.135	399.020	991.680
HC (g/mile)	Highway	0.285	1.007	1.468	0.045	0.047	0.054	0.229	0.280	0.433
	Suburban	1.167	1.296	2.272	0.059	0.053	0.032	0.328	0.405	0.816
	Urban	0.676	1.400	3.240	0.036	0.020	0.000	0.349	0.440	0.960
NOx (g/mile)	Highway	0.229	0.493	0.591	0.484	0.487	0.720	0.686	0.813	1.224
	Suburban	0.582	0.683	0.464	0.598	0.651	0.624	0.938	1.120	2.336
	Urban	0.400	0.400	0.180	0.458	0.480	0.660	0.960	1.240	3.000
CO (g/mile)	Highway	0.443	1.647	2.078	2.666	2.647	3.969	0.278	0.340	0.495
	Suburban	1.823	2.171	2.640	3.326	3.589	3.296	0.375	0.448	0.960
	Urban	1.076	1.780	3.060	2.509	2.540	3.840	0.371	0.520	1.260

* Note: FF = Free Flow, SU/SD = Speed Up / Slow Down, S-G = Stop-and-Go.

Change with Vehicle Model

Generally, fuel economy is one indicator for the evolution of vehicle model and the development of vehicle technology: with the increase of fuel economy, fuel consumption and emissions will decrease [Resources for the Future, 2004]. This model gets the fuel economy data (miles per gallon, mpg) of different vehicle type from 1976 to 2030 (see Figure 4-5). According to the correlation coefficients between annual fuel economy and the fuel economy of MY 2000 (see Figure 4-6), the fuel consumption and emissions of other vehicle models can be calculated from the baseline characteristics inventory for MY 2000. For simplicity, the following assumptions have been made:

- Fuel economy is inversely proportional to fuel consumption and emissions.
- Passenger cars and light trucks are considered separately, but no further distinctions in light-duty vehicle types are made. New technologies are treated as passenger cars.
- The historical data for fuel economy from 1976 to 2005 come from the U.S.

Environmental Protection Agency [EPA, 2005], and the projections after 2005 are linearly extrapolated from the historical data.

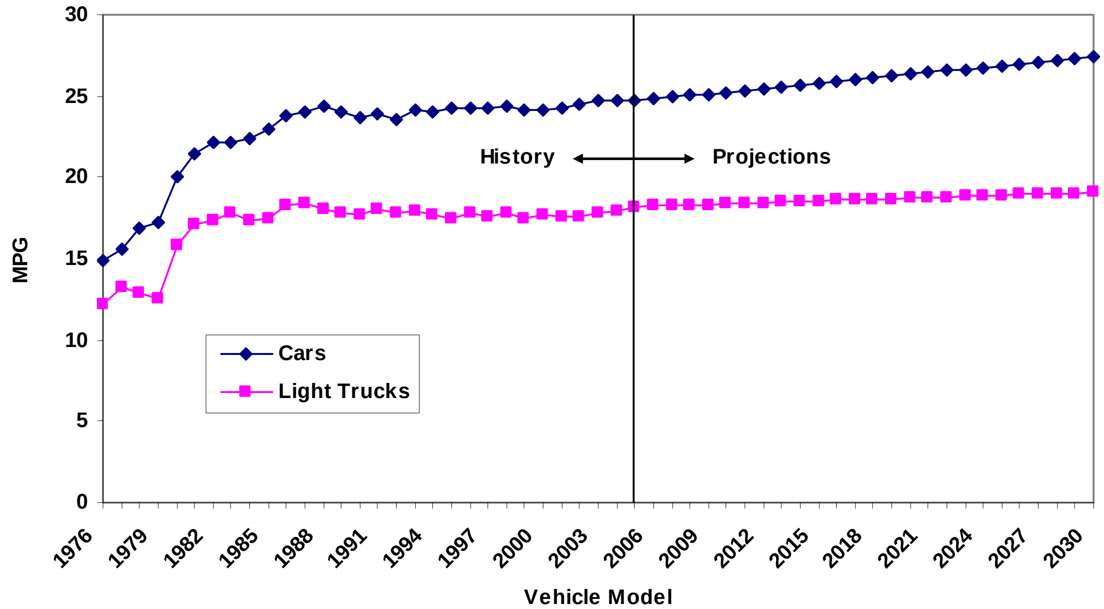

Figure 4-5: Fuel Economy of the U.S. Light-Duty Vehicles

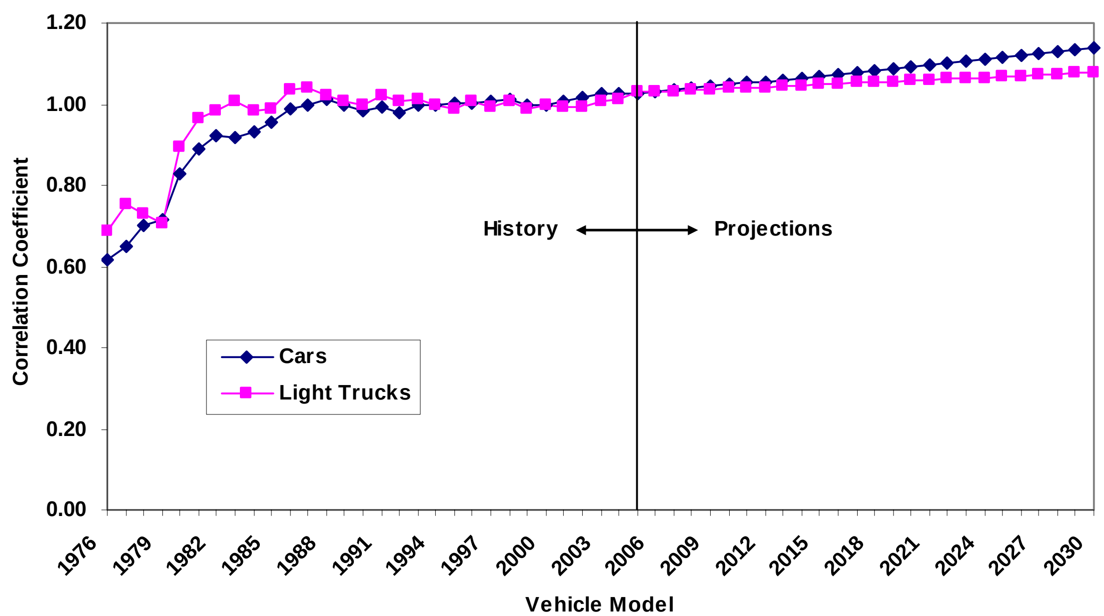

Figure 4-6: Correlation Coefficients for Fuel Economy

From the above two figures, it is obvious that there are four phases for the U.S. light-duty vehicle fuel economy from 1976 to 2005: a rapid increase from 1976 continuing to the mid-1980s; a slow increase extending into the late 1980s; a gradual decline until the mid-1990s; and a period of relatively constant fuel economy since then.

Change with Vehicle Age

The same vehicle will consume more fuel and produce more emissions when it becomes old, and such deterioration can be reflected by fuel economy [Resources for the Future, 2004]. According to the deterioration ratio of fuel economy with vehicle age (the fuel economy ratio between aged vehicle and new vehicle, see Figure 4-7), the fuel consumption and emissions of aged vehicle can be calculated from the baseline characteristics inventory for new vehicle.

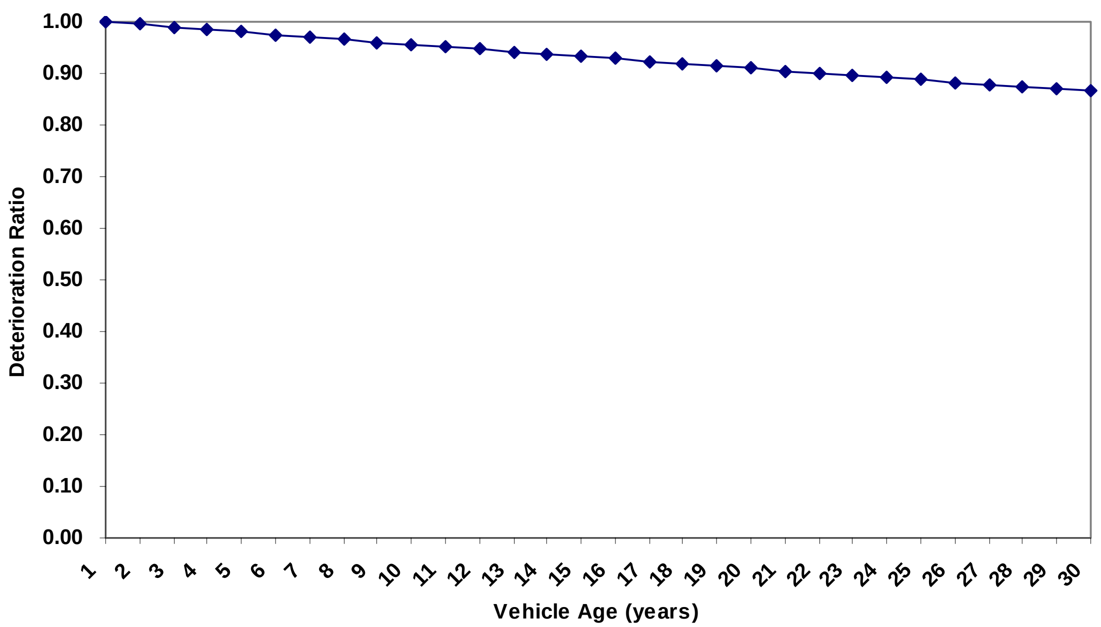

Figure 4-7: Deterioration Ratio for Fuel Economy

For simplicity, two assumptions have been made to get the above figure:

- The lifetime fuel consumption and emissions rates are approximately equivalent for different light-duty vehicle types [Resources for the Future, 2004].
- The fuel economy deterioration rate with aging is taken as -0.5% / year [Kebin He et al., 2002], which means the average fuel economy in a specific year will decrease 0.5% after one-year use.

Change with Transmission Method

There are two transmission types for passenger cars and light trucks: automatic transmission and manual transmission. From the "Driving Segments" matrices, it is known that the fuel consumption and emissions of the same vehicle type with different transmissions are different. According to the automatic / manual ratio in the U.S. light-duty vehicle fleet from 1976 to 2030 (see Figures 4-8 and 4-9) and the baseline characteristics inventory for these two transmissions, the impacts of transmission methods on the fleet fuel consumption and emissions can be calculated.

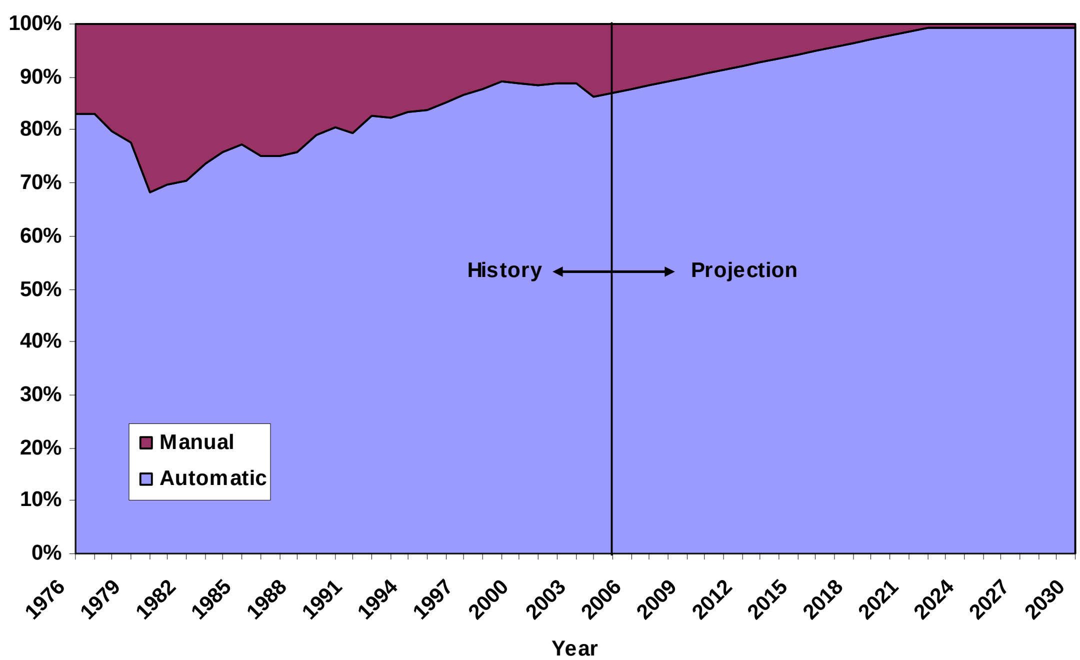

Figure 4-8: The Change of Transmission Methods for Passenger Cars

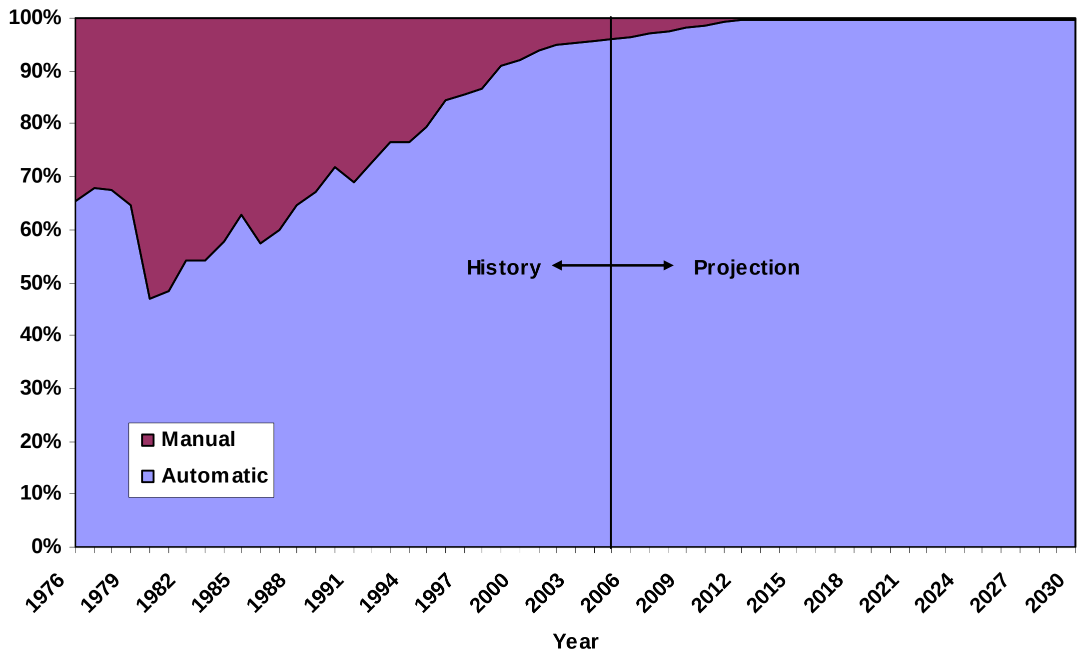

Figure 4-9: The Change of Transmission Methods for Light Trucks

In the above two figures, the historical data from 1976 to 2005 come from the U.S. Environmental Protection Agency [EPA, 2005], and the projections after 2005 are linearly extrapolated from the historical data.

4.3.3 Driving Behavior Model

This model describes the impacts of driving behavior on the fleet fuel consumption and emissions from two aspects: driving speed and vehicle usage.

Driving Speed

During the past several decades, with the application of new safety technologies such as safety belt, air bag and ABS (anti-lock braking system), people tend to drive more aggressively, which means higher average driving speed [Peterson et al., 1995]. Moreover, some studies have shown that younger drivers and worsening traffic will also cause aggressive driving [Krahe et al., 2001; Hennessy et al., 1997]. For simplicity, this model approximately reflects such a change in driving speed through adjusting the composition of three road types (Highway, Suburban and Urban) in vehicle usage (i.e., annual mileage): because the average speed on Highway is higher than those on other two road types (see Chapter 2 and Table 4-5), increasing the proportion of Highway will consequently increase the annual average driving speed, which is accumulated by the products of average speed on each road type and its weight in annual mileage (see Figures 4-10 and 4-11). Further, combining the road type composition with the baseline characteristic inventory in vehicle technology model, the effect of higher average driving speed can be integrated into fuel consumption and emissions of the U.S. light-duty vehicle fleet.

In addition, the following assumptions have been made in this model:

- The composition of three road types in 2005 comes from the Fuel Economy Guide [EPA, 2005].
- From 1982 to 2030, the proportion of Highway vehicle usage grows at 1% / year, while the proportion of Suburban remains unchanged.
- The composition data in other years can be calculated from the above two assumptions.
- The average driving speed has been distinguished under three categories: Free Flow, Speed Up / Slow Down, as well as Stop-and-Go (see Figures 2-2 ~ 2-4).

Table 4-5: Average Speed on Three Road Types (mph)

	FF	SU/SD	S-G
Highway	60.0	45.0	20.0
Suburban	37.5	22.5	7.5
Urban	27.5	15.0	5.0

* Note: FF = Free Flow, SU/SD = Speed Up / Slow Down, S-G = Stop-and-Go.

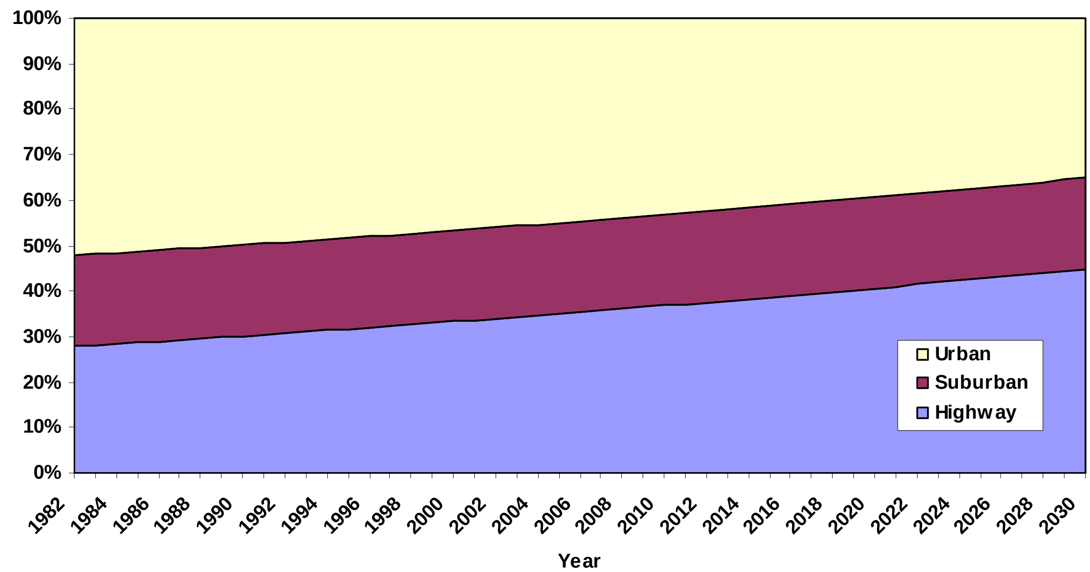

Figure 4-10: The Change of Road Type Composition in Vehicle Usage

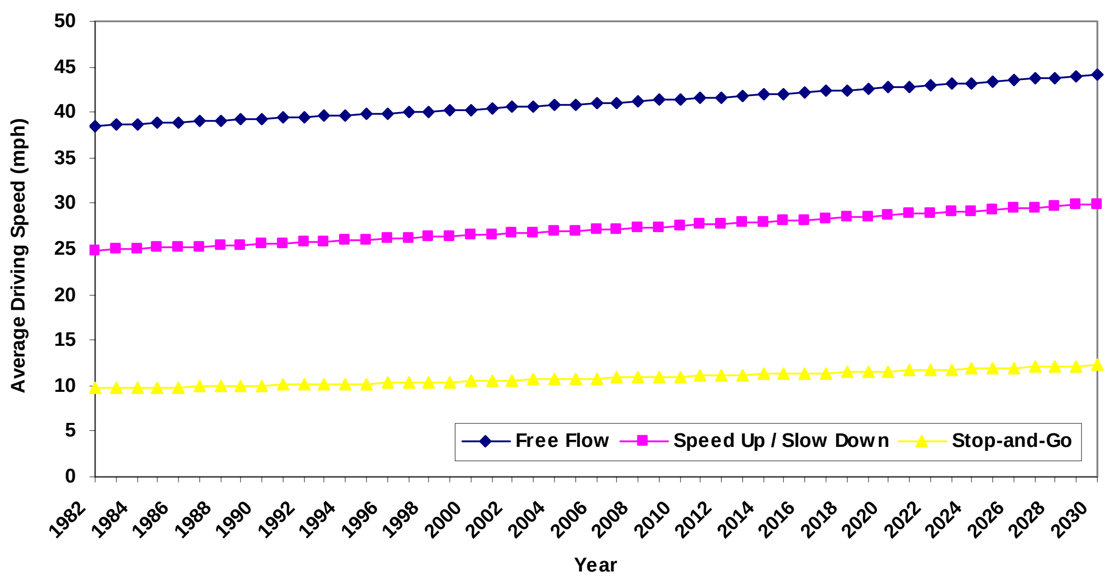

Figure 4-11: The Change of Average Driving Speed

Vehicle Usage

Vehicle usage is defined as the average annual mileage reflecting the amount people use their vehicles. In different years, the vehicle usage may be different because of economic situations and other factors (see Figure 4-12) [ORNL, 2005]. Moreover, with the increase of vehicle age, people tend to use their vehicles less (see Figure 4-13) [ORNL, 2005].

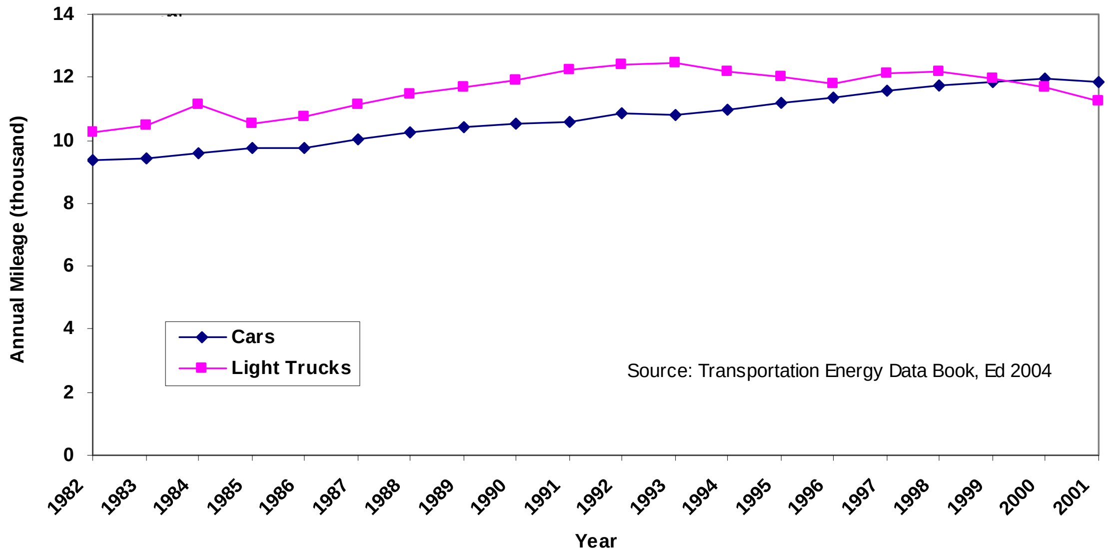

Figure 4-12: The Change of Vehicle Usage with Time (1982-2001)

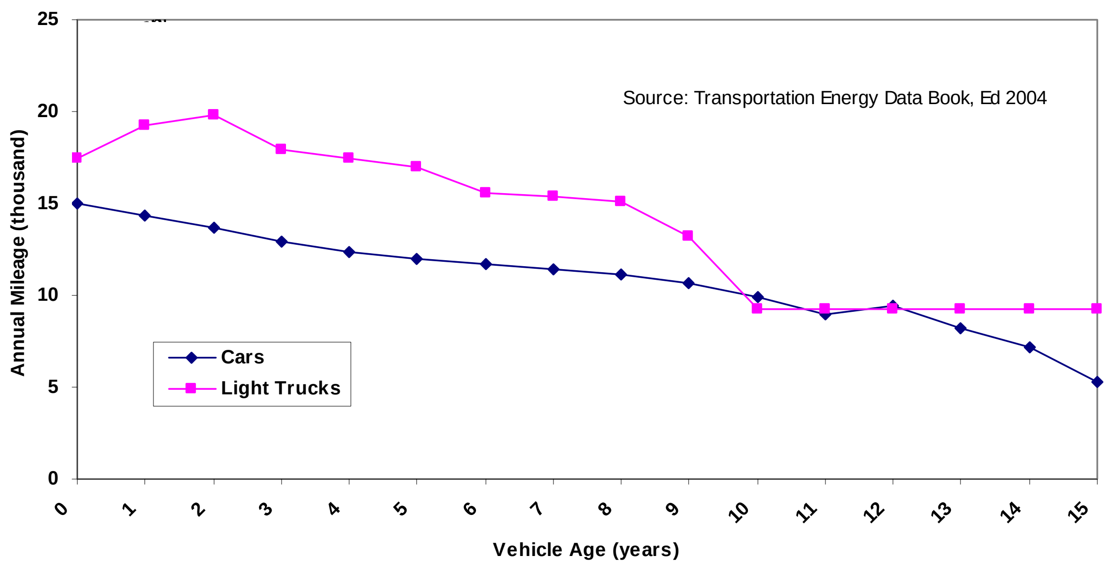

Figure 4-13: The Change of Vehicle Usage with Aging (Estimated in 2001)

With the above two figures, the vehicle usage inventory of different vehicle model in any calendar year from 1982 to 2030 can be calculated by linear extrapolation (see Tables A-4-8 and A-4-9). Because of insufficient data, this model only gives the inventory for passenger cars and light trucks, and no further classification is made. As for new technologies, their usage is taken as the same as passenger cars.

4.3.4 Traffic Congestion Model

This model aims to quantify the change of traffic congestion with time. According to the 2005 Urban Mobility Report [TTI, 2005], from 1982 to 2003, the traffic congestion in the U.S. has become worse in terms of both total delay time and the composition of congestion levels (see Figure 1-3).

For simplicity, the traffic congestion model (see Figure 4-14) can be developed from the 2005 Urban Mobility Report under the following assumptions (similar to the assumptions in Chapter 3):

- To link the congestion levels in the above figure with the "driving segments" in this thesis, it is assumed that: Free Flow = Uncongested + Moderate; Speed Up/Slow Down = Heavy + Severe; Stop-and-Go = Extreme.
- The composition of congestion levels in other years can be linearly interpolated or extrapolated from the data of 1982 and 2003 in the above figure.
- All the composition data are based on mileage.

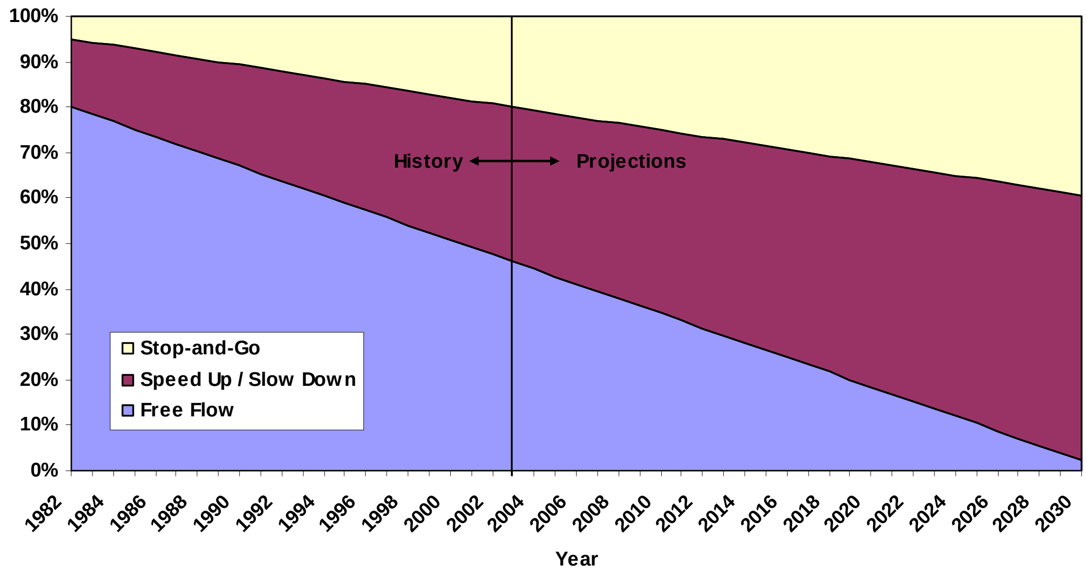

Figure 4-14: Percentage Composition of Congestion Levels

4.4 Identifying the Impacts of Worsening Traffic

Based on the above models and assumptions for the Reference Case, this section analyzes the total impacts of four major factors (fleet population, vehicle technology, driving behavior and traffic congestion) on fuel consumption and emissions of the U.S. light-duty vehicle fleet from 1982 to 2030 (common time range for four models). Further, the impacts of worsening traffic can be extracted from the total impacts through defining the Static Case and Base Cases. After that, sensitivity analyses are made to identify the key factors offsetting these energy and environmental impacts of worsening traffic in the future 27 years (2004-2030, common projection range for four models).

4.4.1 Total Impacts Calculation

There are three steps in order to get the total impacts of four major factors on the fleet fuel consumption and emissions:

First, developing the baseline characteristics inventory (MY 2000 and 0-year-old) into real characteristics inventory for different vehicle type and different vehicle model in any calendar year from 1982 to 2030 (see Table A-4-10, the example of fuel consumption for Two-seater Cars). According to the features of the baseline characteristics inventory (see Tables 4-2 ~ 4-4), the impacts of vehicle model, vehicle year and transmission methods (see Figures 4-5 ~ 4-9), the composition of road types (see Figure 4-10), as well as the composition of congestion levels (see Figure 4-14) should be considered to build the real characteristics inventory. In another word, the vehicle technology model, driving behavior model and traffic congestion model need to be integrated in this step.

Second, for each vehicle type, multiplying the vehicle population inventory (see Table A-4-7), vehicle usage inventory (see Table A-4-8) and real characteristics inventory (see Table A-4-10), the fuel consumption and emissions of all the vehicles belonging to a specific model in any calendar year from 1982 to 2030 can be calculated (see Table A-4-11, the example of fuel consumption for Two-seater Cars). This calculation process is easy to complete because these three of inventories share the same structure.

Finally, the total energy and environmental impacts on the U.S. light-duty vehicle fleet can be determined by summing the fuel consumption and emissions of 13 light-duty vehicle types. The results for the fleet fuel consumption and emissions are shown as quantitative curves or percentage composition (see Figures 4-15 ~ 4-25 and Figures A-4-5 ~ A-4-24).

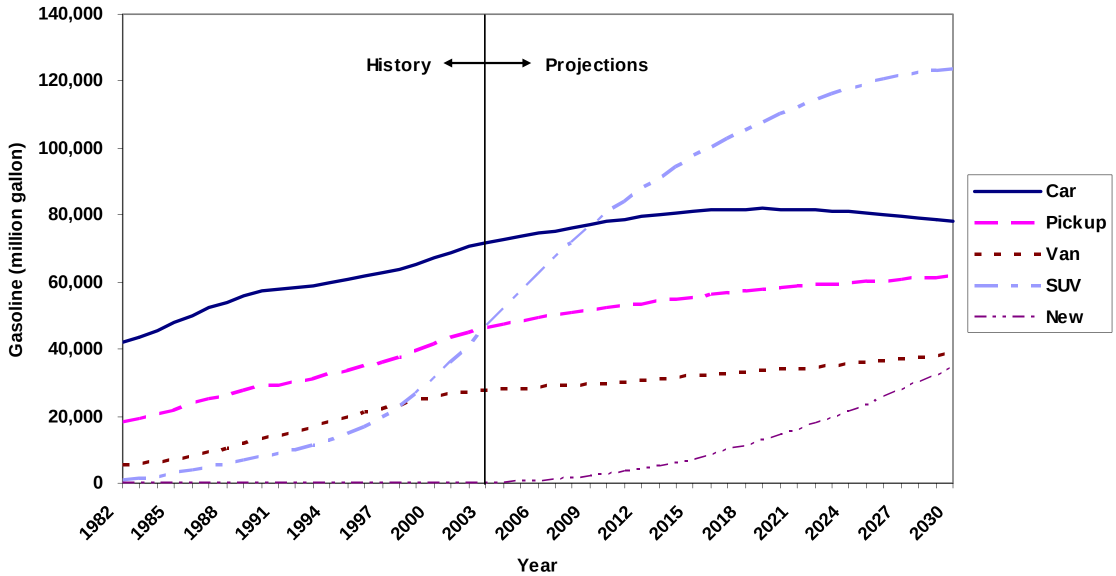

Figure 4-15: Fuel Consumption of the U.S. Light-Duty Vehicle Fleet (Version 2)

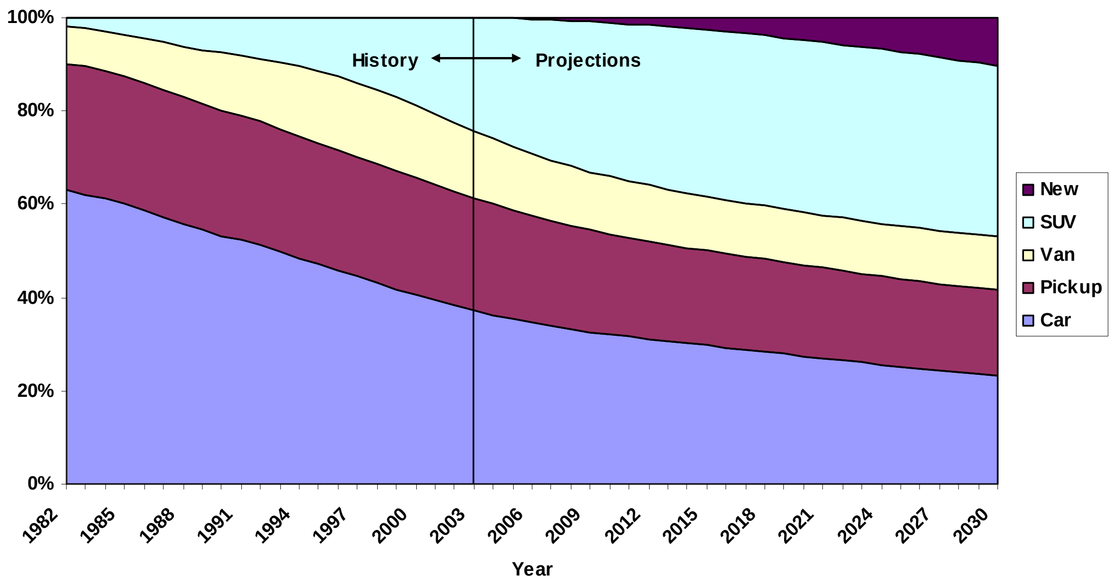

Figure 4-16: Percentage Composition of the U.S. LDV Fleet Fuel Consumption (Version 2)

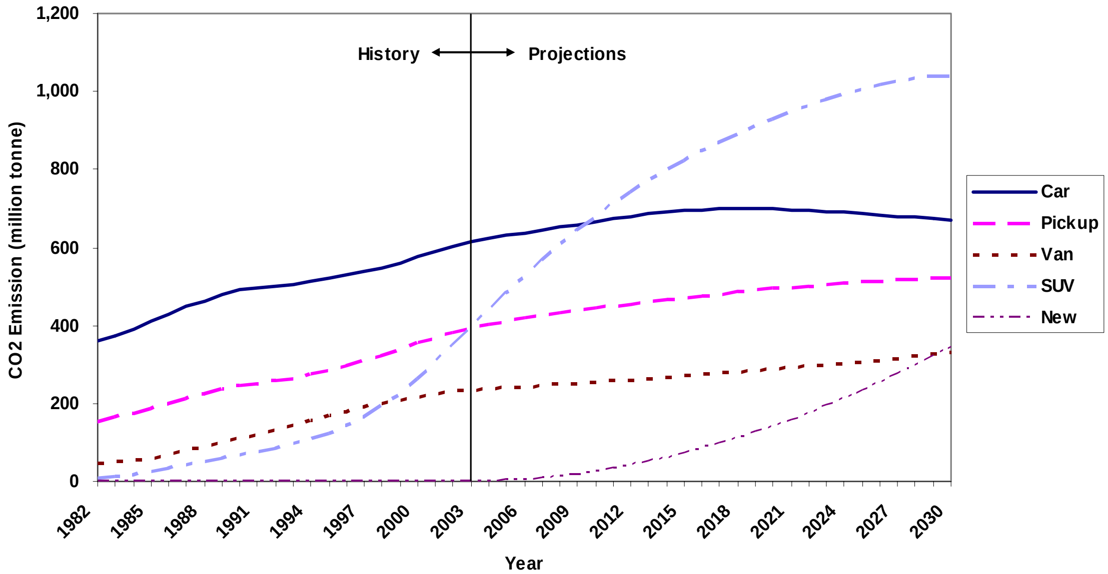

Figure 4-17: CO_2 Emission of the U.S. Light-Duty Vehicle Fleet (Version 2)

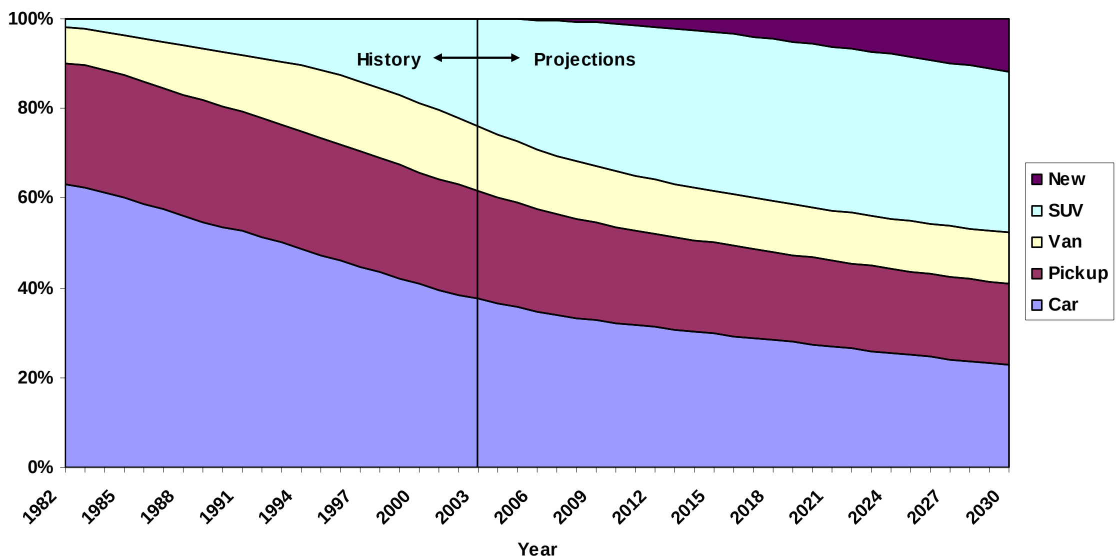

Figure 4-18: Percentage Composition of the U.S. LDV Fleet CO_2 Emission (Version 2)

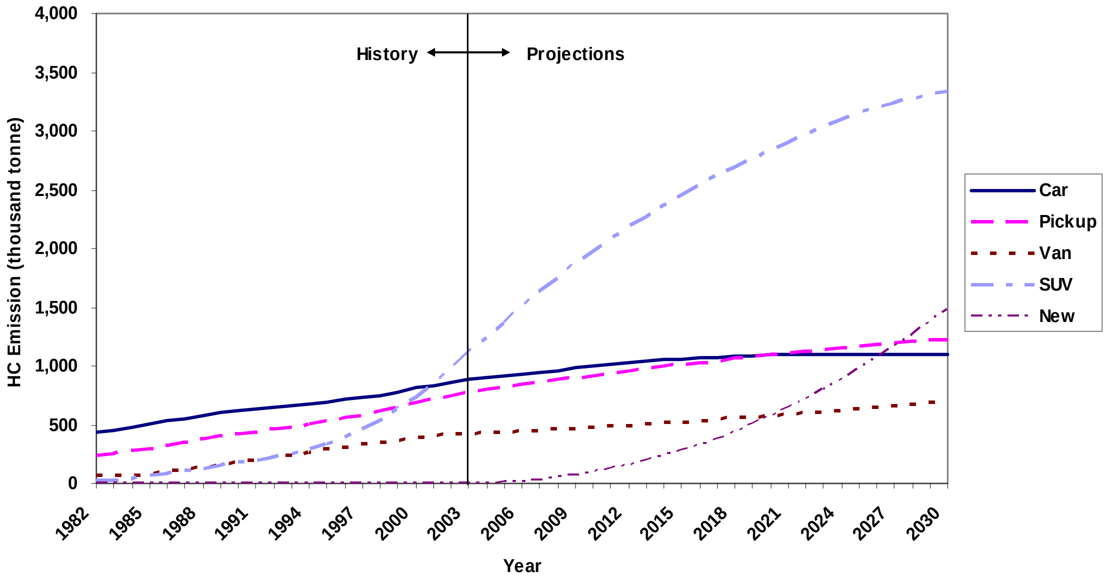

Figure 4-19: HC Emission of the U.S. Light-Duty Vehicle Fleet (Version 2)

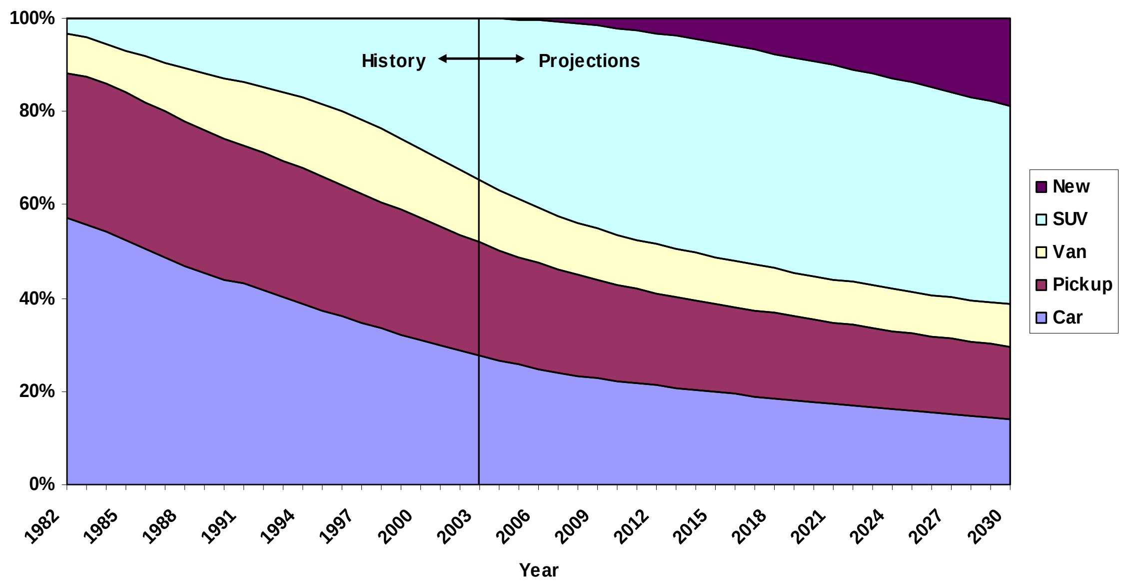

Figure 4-20: Percentage Composition of the U.S. LDV Fleet HC Emission (Version 2)

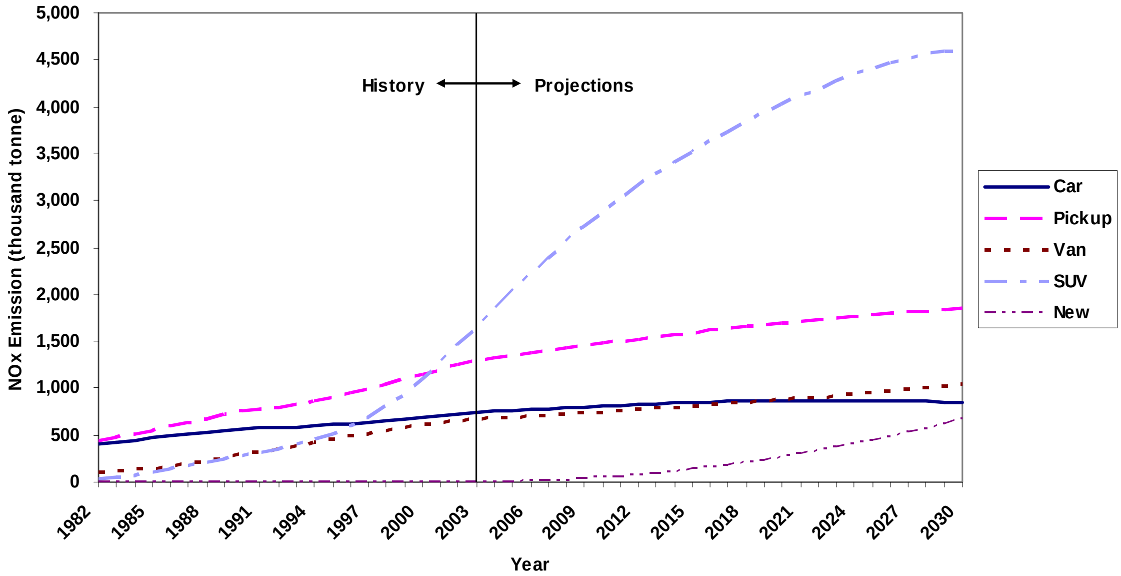

Figure 4-21: NO_X Emission of the U.S. Light-Duty Vehicle Fleet (Version 2)

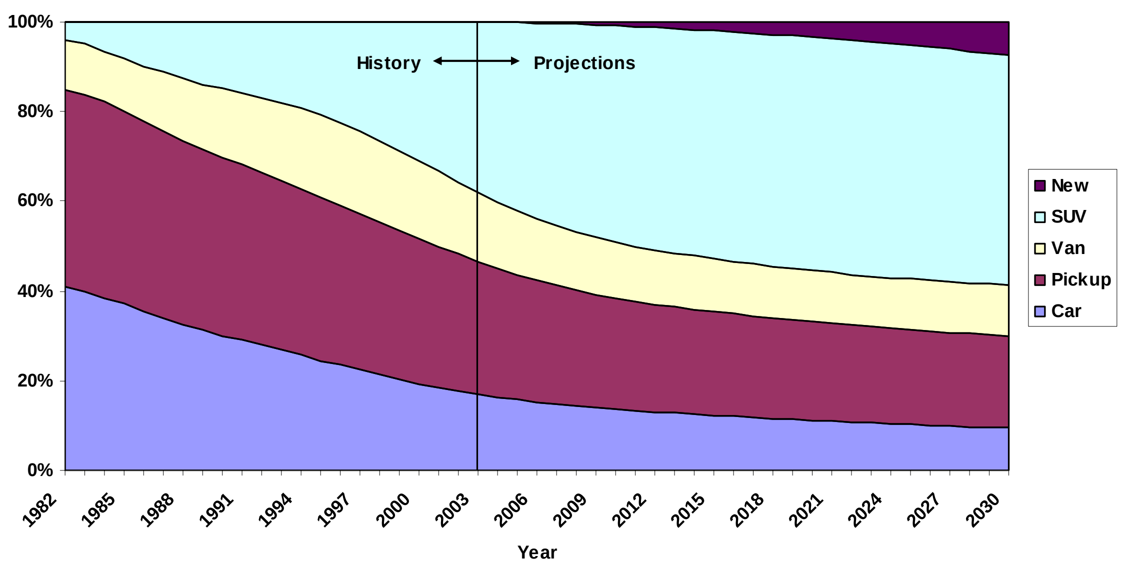

Figure 4-22: Percentage Composition of the U.S. LDV Fleet NO_X Emission (Version 2)

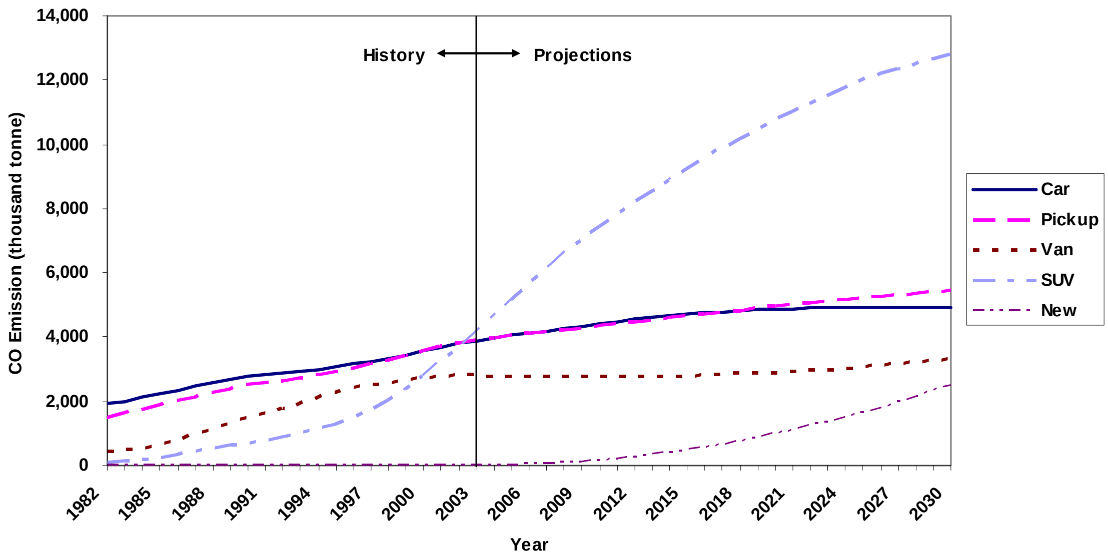

Figure 4-23: CO Emission of the U.S. Light-Duty Vehicle Fleet (Version 2)

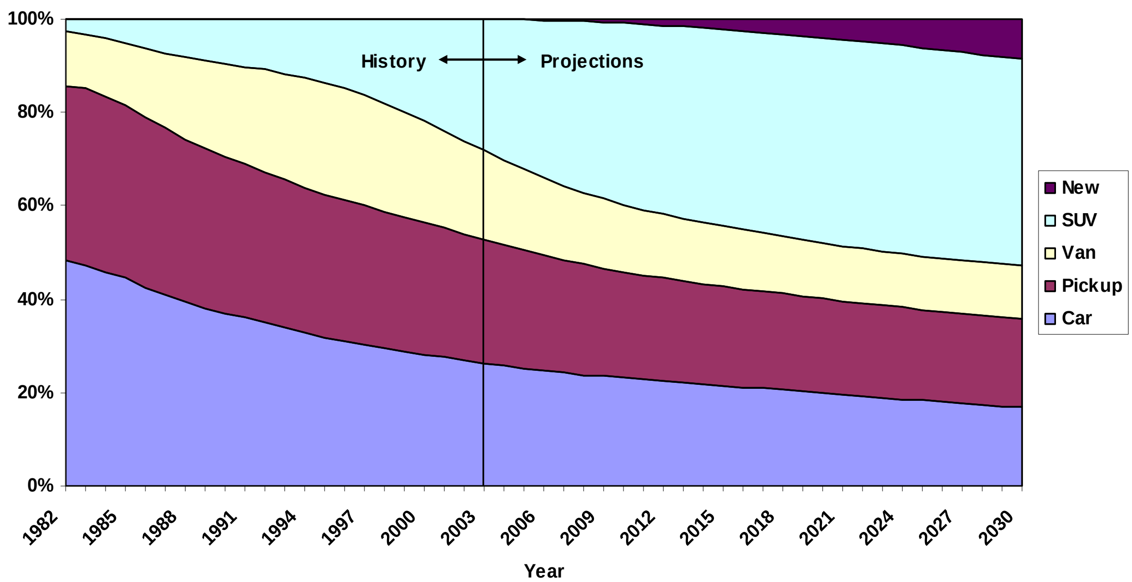

Figure 4-24: Percentage Composition of the U.S. LDV Fleet CO Emission (Version 2)

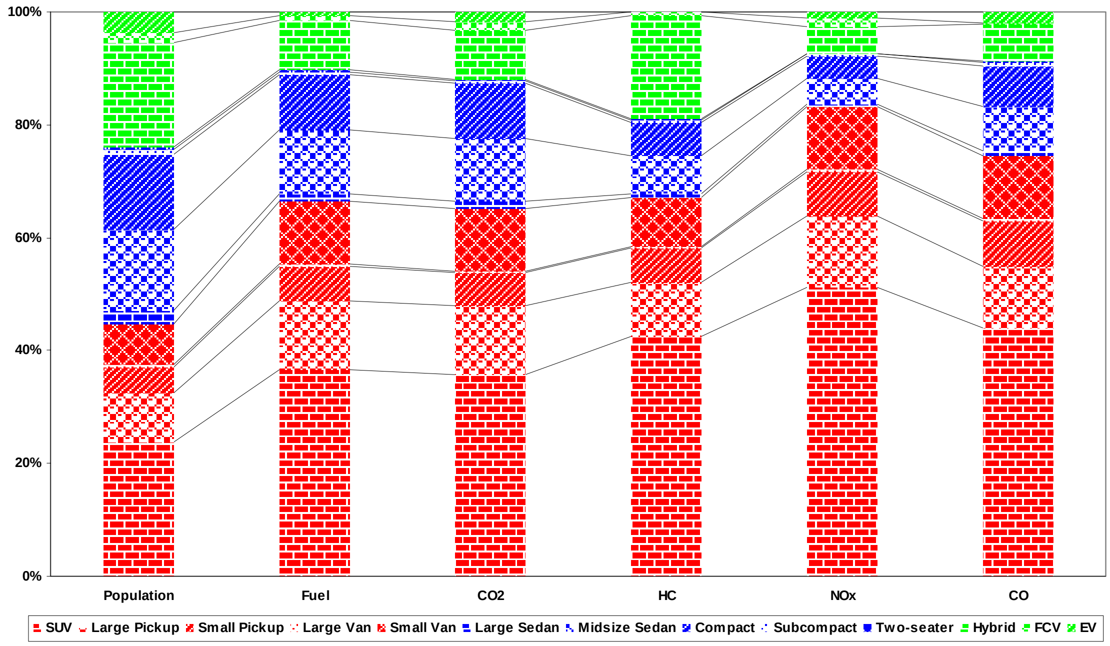

Figure 4-25: Percentage Composition for Vehicle Population, Fuel Consumption and Emissions in 2030

From the above graphs, three major conclusions can be drawn:

- If trends from the 1970s and early 2000 continue, SUV will be the largest source for fuel consumption and emissions of the U.S. light-duty vehicle fleet. Fuel consumption and CO_2 emission of SUV will exceed those of all passenger cars after 2010.
- Similarly, the fuel consumption and CO_2 emissions of all light trucks will increase nearly 85% because of the strong growth from SUV, while the fuel consumption and CO_2 emissions of passenger cars will only increase 9%.
- Hybrid can considerably reduce fuel consumption and emissions of the U.S. light-duty vehicle fleet: by the end of 2030, SUV will account for roughly 25% of the fleet population but account for nearly 40% of total fuel consumption and CO_2 emission, while Hybrid will account for roughly 20% of the fleet population but account for only 10% of total fuel consumption and CO_2 emission.

4.4.2 Impacts of Worsening Traffic

The above calculations give the fuel consumption and emissions of the U.S. light-duty vehicle fleet, which can be treated as the total impacts of four major factors including fleet population, vehicle technology, driving behavior and traffic congestion. Any change of these factors will affect overall fleet composition, fuel consumption and emissions.

Specifically, the traffic congestion in the Reference Case will continue to become worse from 2004 to 2030 (see Figure 4-14), and assessing the impacts of worsening traffic is one core task of this thesis. In order to identify the impacts of worsening traffic from the fleet fuel consumption and emissions as well as compare these impacts with those from the changes of other factors, one "Static Case" and four "Base Cases" are defined in Table 4-6.

Table 4-6: Definition of Static Case and Base Cases

Static Case	*Fleet population (LDV new sales), vehicle technology (average fuel economy), driving behavior (average driving speeds) and traffic congestion (congestion level composition) will not change from 2004-2030; Others are the same with Reference Case.*
Base Case 1	*Fleet population will change as Reference Case from 2004-2030, i.e., LDV new sales increase 0.8% per year; Others are the same with Static Case.*
Base Case 2	*Vehicle technology will change as Reference Case from 2004-2030, i.e., average fuel economy of cars and light trucks increase 0.11 mpg and 0.03 mpg per year respectively; Others are the same with Static Case.*
Base Case 3	*Driving behavior will change as Reference Case from 2004-2030, i.e., average driving speeds under FF, SU/SD and S-G increase 2-3 mph from 2004-2030; Others are the same with Static Case.*
Base Case 4	*Traffic congestion will change as Reference Case from 2004-2030, i.e., the percentage for FF in annual milage decreases from 44% to 2% during 2004-2030; Others are the same with Static Case.*

Base Case 1 is different from the Static Case only because of the change of fleet population from 2004 to 2030. It is obvious that the difference between the fleet fuel consumption and emissions in these two case scenarios exactly reflects the impacts of fleet population change. Similarly, from Static Case to Base Case 2, the change of fleet fuel consumption and emissions reflects the impacts of vehicle technology improvements;

From Static Case to Base Case 3, the change of fleet fuel consumption and emissions reflects the impacts of driving behavior change (higher average speeds); From Static Case to Base Case 4, the change of fleet fuel consumption and emissions reflects the impacts of traffic congestion change (worsening traffic); And from Static Case to Reference Case, the total impacts of the changes of four factors (Base Cases 1-4) are reflected. In other words, the Static Case provides a baseline to compare the impacts caused by the changes of different factors, and these impacts can be quantified by the difference of fleet fuel consumption and emissions between Static Case and Base Cases (see Table 4-7).

According to the above definition and analysis as well as the models for four factors, the fuel consumption and emissions of the U.S. light-duty vehicle fleet in the Static Case and Base Cases can be calculated as those in the Reference Case. Further, the impacts of worsening traffic and the impacts of other factors' changes can be visualized by the areas among quantitative curves for the fleet fuel consumption and emissions in different case scenarios (see Figures 4-26 ~ 4-35).

Table 4-7: Case Scenarios and Impacts Analysis

Static Case	→	**Base Case 1**	*Impacts of the change of fleet population (more new sales).*
Static Case	→	**Base Case 2**	*Impacts of the change of vehicle technology (better fuel economy).*
Static Case	→	**Base Case 3**	*Impacts of the change of driving behavior (higher driving speed).*
Static Case	→	**Base Case 4**	*Impacts of the change of traffic congestion (worsening traffic).*
Static Case	→	**Reference Case**	*Total impacts of the changes of four factors (Base Case 1-4).*

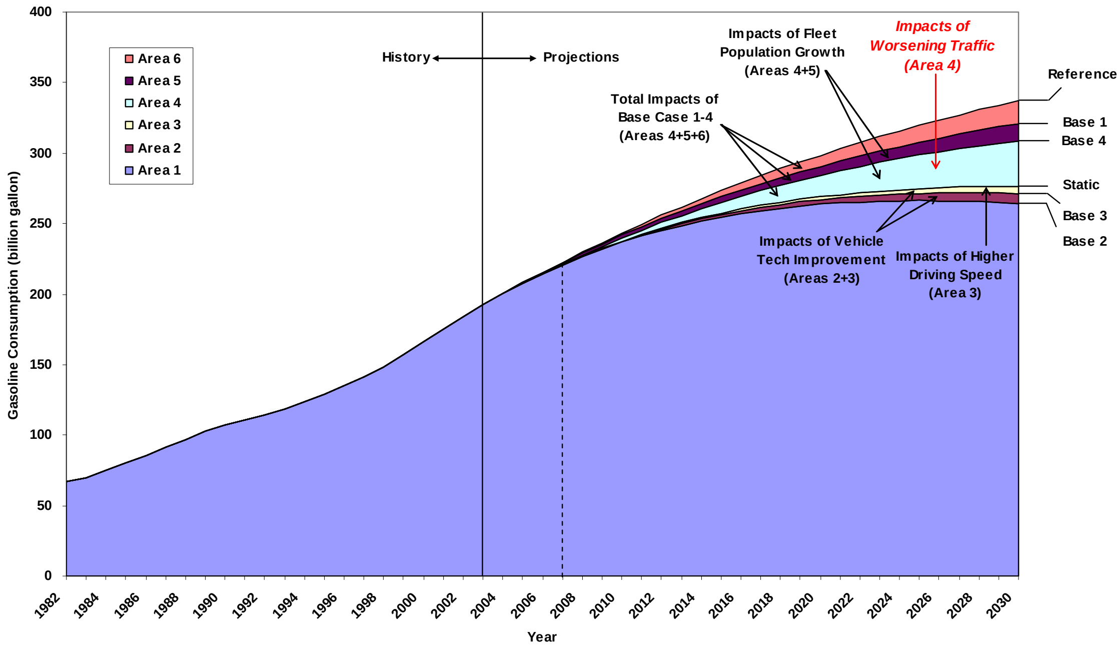

Figure 4-26: Impacts Analysis for Fuel Consumption of the U.S. Light-Duty Vehicle Fleet

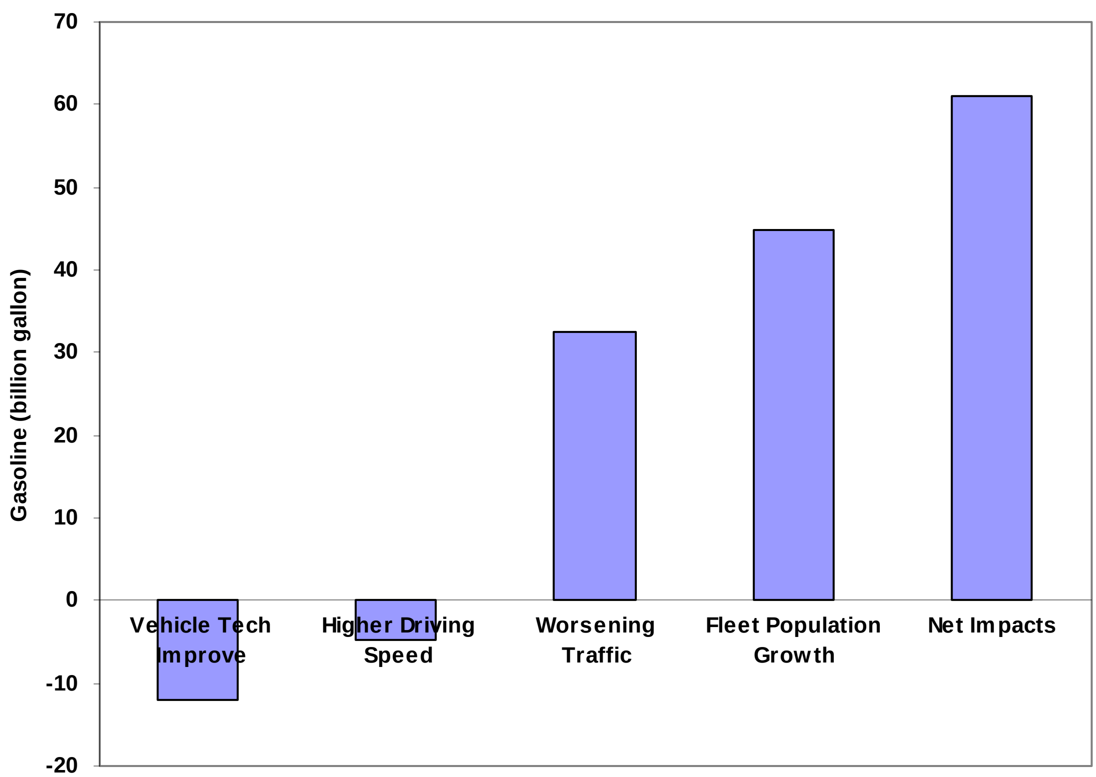

Figure 4-27: Impacts Analysis for Fuel Consumption in 2030 (Change to Static Case)

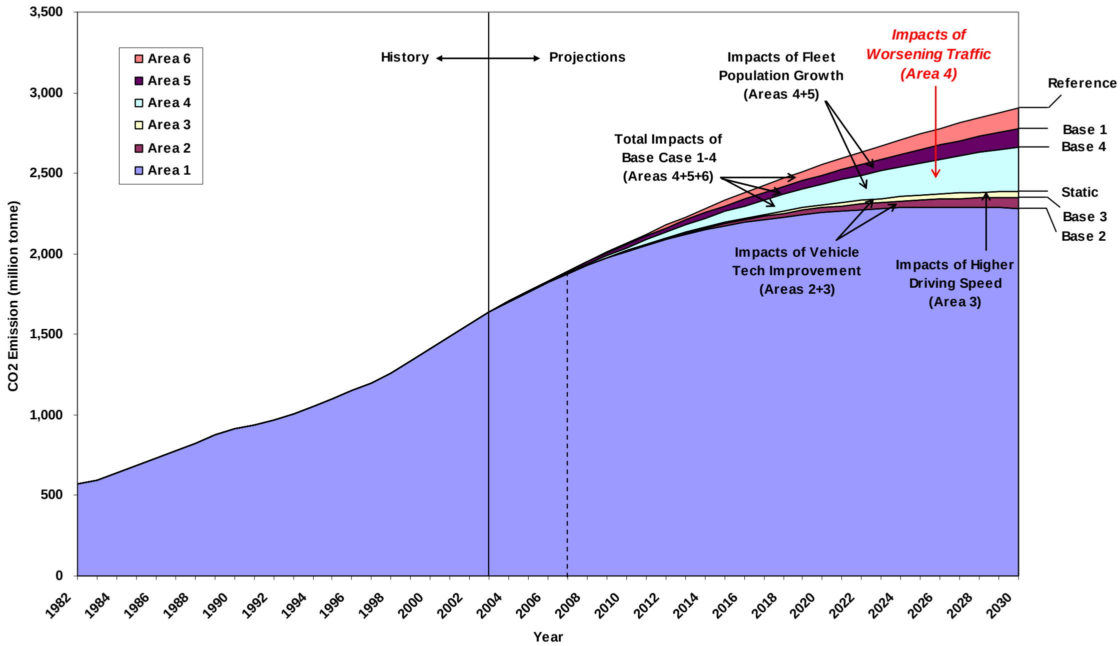

Figure 4-28: Impacts Analysis for CO_2 Emission of the U.S. Light-Duty Vehicle Fleet

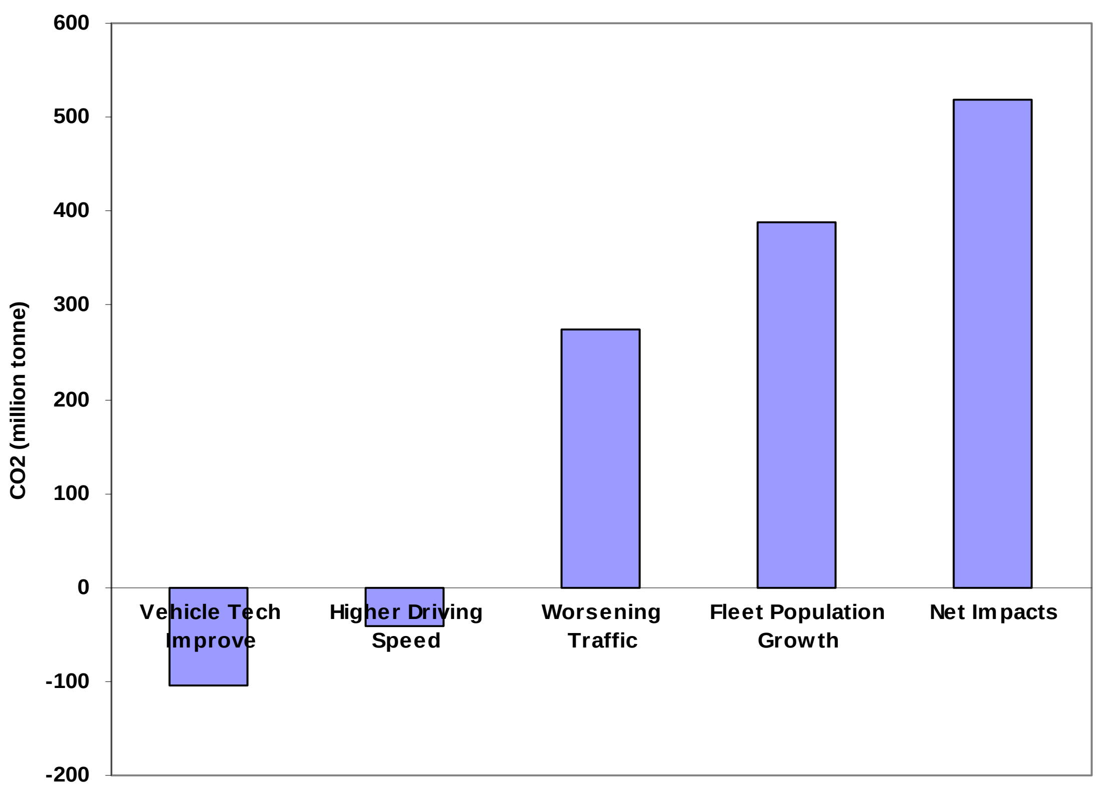

Figure 4-29: Impacts Analysis for CO_2 Emission in 2030 (Change to Static Case)

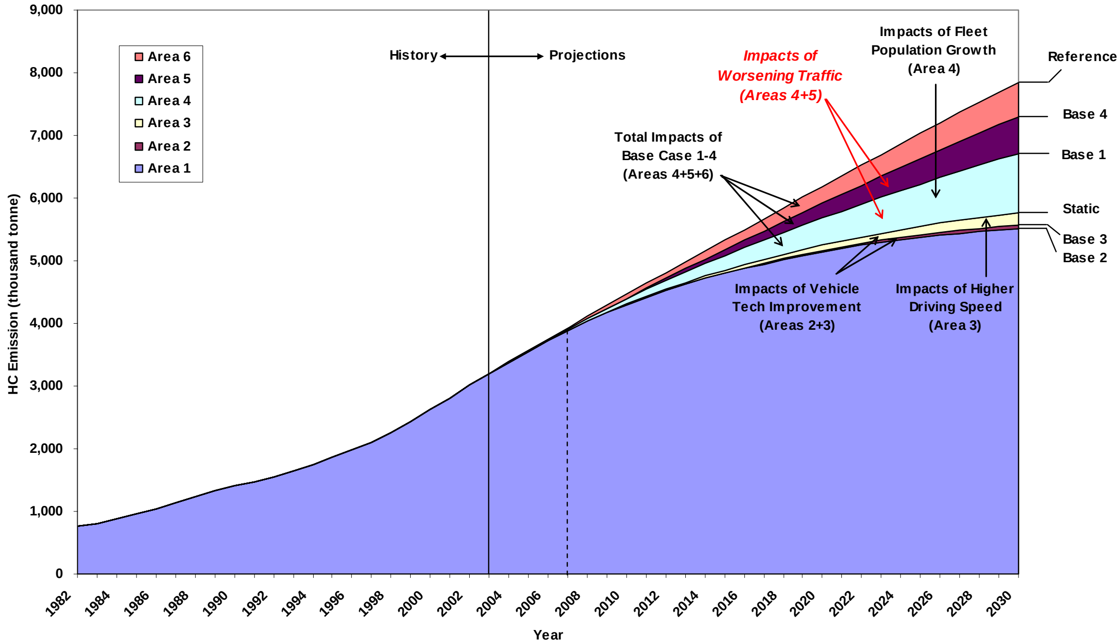

Figure 4-30: Impacts Analysis for HC Emission of the U.S. Light-Duty Vehicle Fleet

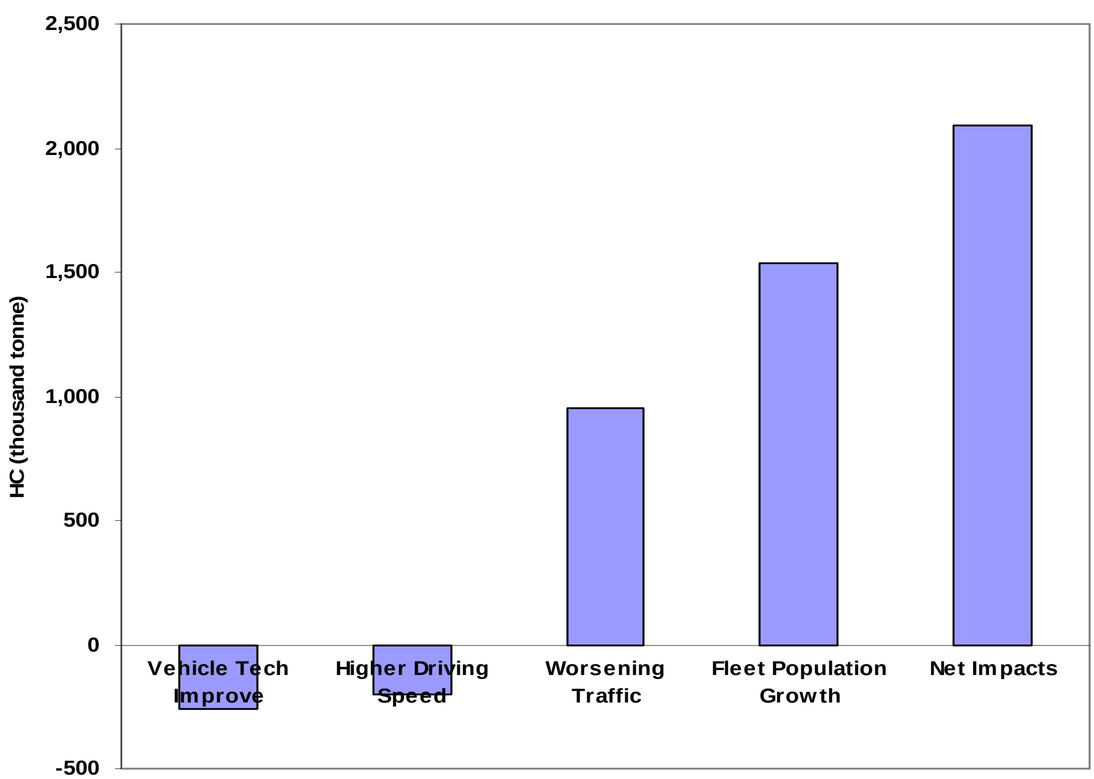

Figure 4-31: Impacts Analysis for HC Emission in 2030 (Change to Static Case)

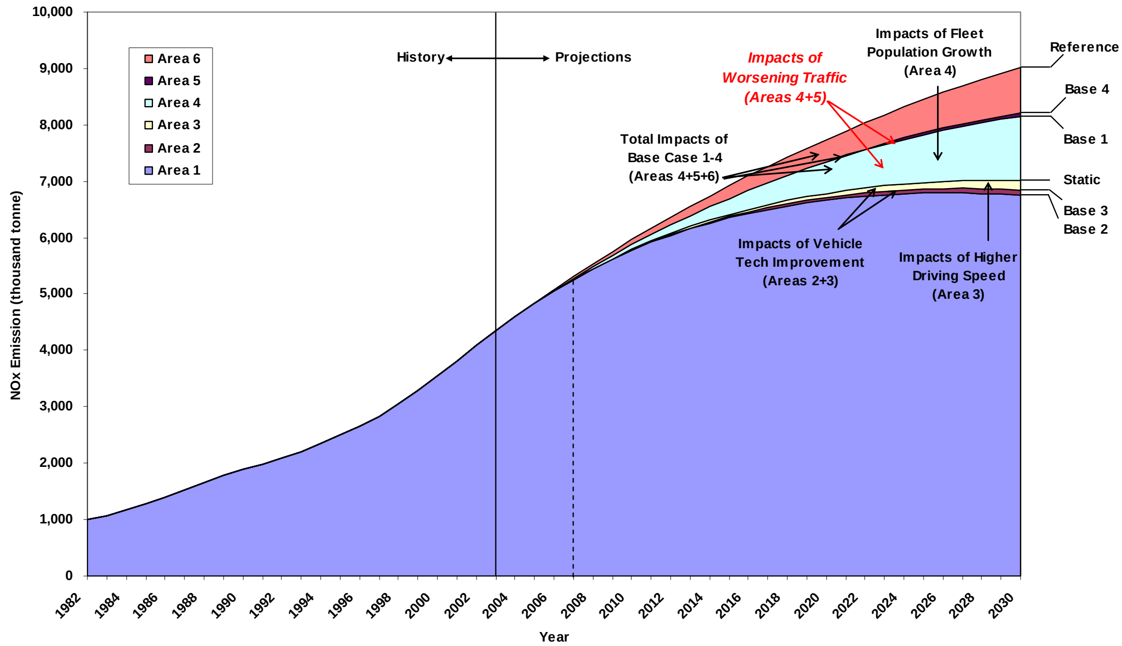

Figure 4-32: Impacts Analysis for NO_X Emission of the U.S. Light-Duty Vehicle Fleet

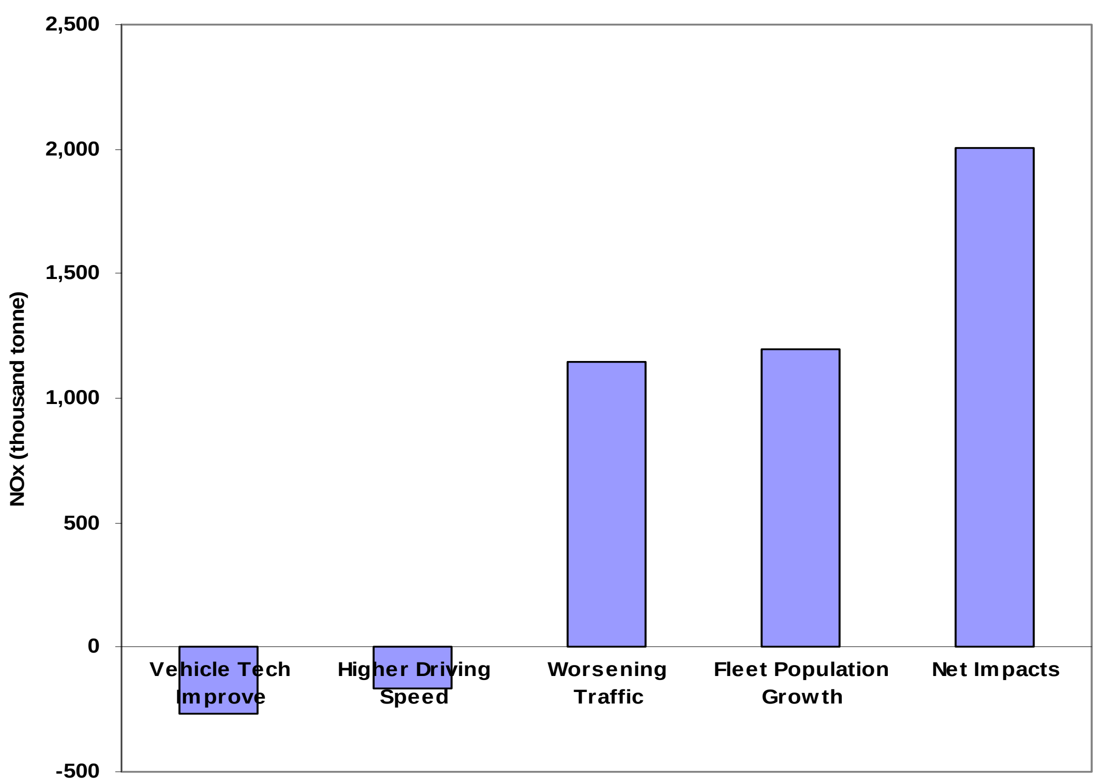

Figure 4-33: Impacts Analysis for NO_X Emission in 2030 (Change to Static Case)

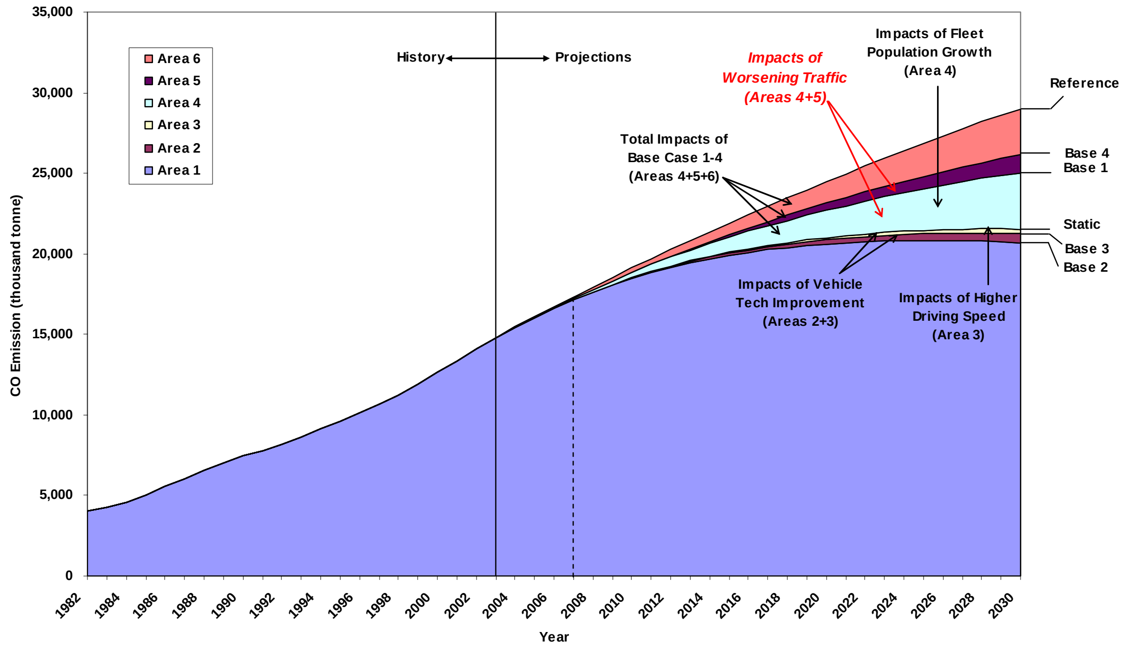

Figure 4-34: Impacts Analysis for CO Emission of the U.S. Light-Duty Vehicle Fleet

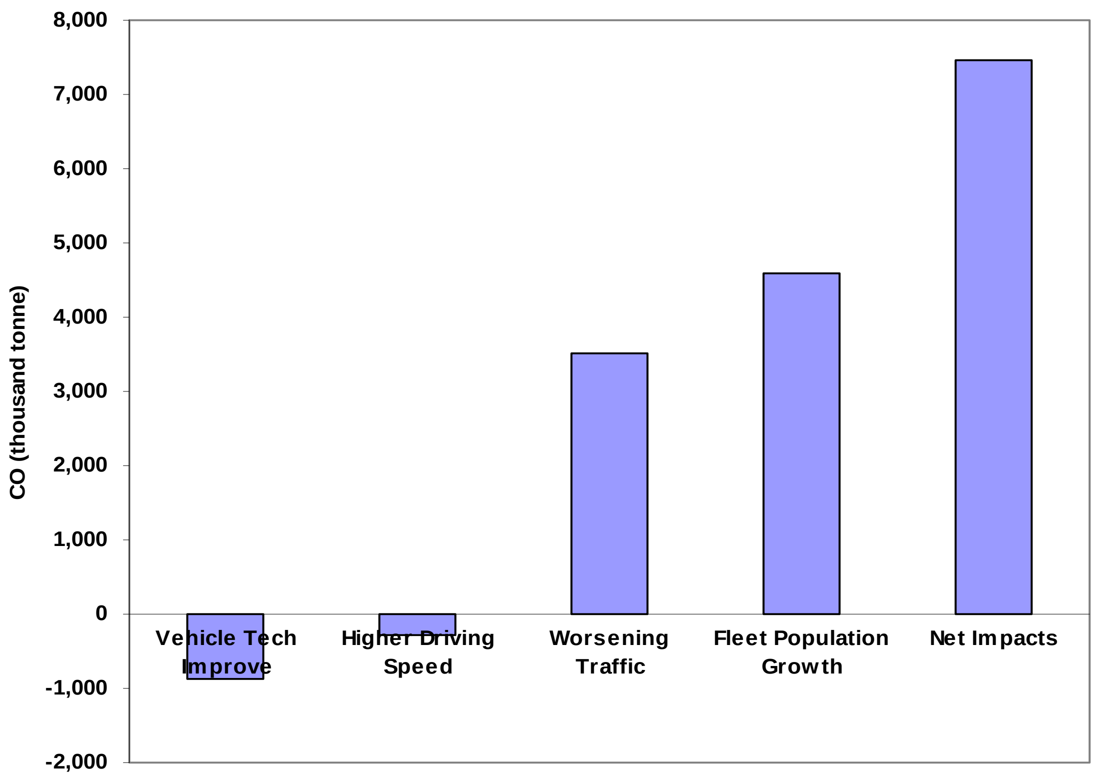

Figure 4-35: Impacts Analysis for CO Emission in 2030 (Change to Static Case)

From Figures 4-26 ~ 4-35, several conclusions are made as below:

- The divergence between different case scenarios generally begins in 2008, which means about 4 years before the changes of fleet fuel consumption and emissions are visible.
- The fleet fuel consumption and emissions in Base Cases 2 (Better Fuel Economy) and 3 (Higher Driving Speed) are lower than those of the Static Case, which means that improved average fuel economy and higher average driving speed will decrease the fuel consumption and emissions of the U.S. light-duty vehicle fleet. Specifically, in 2030, Base Case 2 (Better Fuel Economy) can save 12 billion-gallon gasoline and reduce 105 million-tonne CO_2 emission; and Base Case 3 (Higher Driving Speed) can save 5 billion-gallon gasoline and reduce 41 million-tonne CO_2 emission (see Figures 4-27 and 4-29). However, it should be clarified that such a relationship between higher average driving speed and better fleet performance may not be valid for other driving behavior assumptions than those in the Reference Case. Higher driving speed in Base Case 3 only reduces fuel consumption and emissions since vehicles are operating closer to their optimal performance point.
- The fleet fuel consumption and emissions in Base Cases 1 (More New Sales) and 4 (Worsening Traffic) are higher than those of the Static Case, which means that the growth of light-duty vehicle new sales and worsening traffic will increase the fuel consumption and emissions of the U.S. light-duty vehicle fleet. Specifically, in 2030, Base Case 1 (More New Sales) additionally brings 45 billion-gallon gasoline as well as 388 million-tonne CO_2 emission, and Base Case 4 (Worsening Traffic) additionally brings 32 billion-gallon gasoline as well as 274 million-tonne CO_2 emission (see Figures 4-27 and 4-29).
- For the fleet fuel consumption and CO_2 emission, the impacts of four changes

can be ranked from high to low (absolute values): light-duty vehicle new sales change → worsening traffic → vehicle technology change → driving behavior change.

- For the fleet HC, CO and NO_X emissions, the impacts of four changes can be ranked from high to low (absolute values): worsening traffic → light-duty vehicle new sales change → vehicle technology change → driving behavior change.
- The above two ranks show that fleet population and traffic congestion are two most important factors for the energy and environmental performance of the U.S. light-duty vehicle fleet. That is to say, the undesirable impacts of light-duty vehicle new sales change and worsening traffic exceed the desirable impacts of vehicle technology change and driving behavior change. Specifically, in 2030, the improved vehicle technology (Base Case 2) would only offset 1/3 of the fuel consumption increased from worsening traffic (Base Case 4) (see Figure 4-27). Therefore, the fleet fuel consumption and emissions in Reference Case, which integrates the impacts of these four changes, are higher than those in Static Case.

4.4.3 Sensitivity Analysis

Through defining the Static Case and Base Cases, the impacts of worsening traffic are extracted from the fleet performance and then are compared with the impacts caused by the changes of other factors. Actually, the Static Case and Base Cases represent an inner sensitivity analysis because they just change several assumptions in the Reference Case. Based on that, this thesis carries out more sensitivity analysis in order to further identify the most important factors for the fuel consumption and emissions of the U.S. light-duty vehicle fleet.

As discussed before, fleet population, traffic congestion, vehicle technology and driving behavior are four major factors determining the fleet fuel consumption and emissions. Centered on these four factors, this thesis designs six groups (14 scenarios) of sensitivity analysis for the Reference Case: Groups 1 and 2 focusing on fleet population, Group 3 focusing on traffic congestion, Group 4 focusing on vehicle technology, as well as Groups 5 and 6 focusing on driving behavior (see Table 4-8).

The previous total impacts calculation also concludes that SUV will be the largest source for the fuel consumption and emissions of the U.S. light-duty vehicle fleet and that Hybrid can remarkably reduce the fleet fuel consumption and emissions (see Figures 4-15 ~ 4-25 and Figures A-4-5 ~ A-4-24). Therefore, Groups 1 and 2 intentionally deal with the population change of these two vehicle types.

Group 3 (3.1-3.4) changes the traffic assumption (2004-2030) in the Reference Case and tries to identify the influence of different traffic assumptions on the fuel consumption and emissions of the U.S. light-duty vehicle fleet. Specifically, Reference Case assumes the traffic situations from 2004 to 2030 will become "worse" (Free Flow: 2% in 2030), while Sensitivity Analysis 3.1-3.4 assume the traffic situations after 2003 will become "half worse" (Free Flow: 24% in 2030), "same with 2003" (Free Flow: 46% in 2030), "half better" (Free Flow: 68% in 2030) and "better" (Free Flow: 90% in 2030) respectively (see Figures 4-36 ~ 4~40).

Moreover, driving speed and vehicle usage are two major aspects of driving behavior, but vehicle usage does not included in the impacts analysis because it is difficult to be quantitatively controlled. In the sensitivity analysis, Group 6 is specifically designed for the change of vehicle usage.

Table 4-8: Six Groups of Sensitivity Analysis for the Reference Case (14 Scenarios)

GROUP 1	**Sensitivity Analysis 1.1**	*SUV annual new sales share decrease 10% (absolute value) after 2004*
	Sensitivity Analysis 1.2	*SUV annual new sales share decrease 20% (absolute value) after 2004*
GROUP 2	**Sensitivity Analysis 2.1**	*Hybrid, EV and FCV penetration 1.5 times faster after 2004*
	Sensitivity Analysis 2.2	*Hybrid, EV and FCV penetration 2.0 times faster after 2004*
GROUP 3	**Sensitivity Analysis 3.1**	*Congestion levels become half worse after 2004*
	Sensitivity Analysis 3.2	*Congestion levels become the same after 2004*
	Sensitivity Analysis 3.3	*Congestion levels become half better after 2004*
	Sensitivity Analysis 3.4	*Congestion levels become better after 2004*
GROUP 4	**Sensitivity Analysis 4.1**	*Vehicle technology develops faster after 2004 (annual growth 2 times)*
	Sensitivity Analysis 4.2	*Vehicle technology develops slower after 2004 (annual growth 1/2 times)*
GROUP 5	**Sensitivity Analysis 5.1**	*Driving behavior becomes more aggressive after 2004 (2030 Free Flow Average Speed = 48 mph)*
	Sensitivity Analysis 5.2	*Driving behavior becomes much more aggressive after 2004 (2030 Free Flow Average Speed = 53 mph)*
GROUP 6	**Sensitivity Analysis 6.1**	*Vehicle usage increases faster after 2004 (change rate 2 times)*
	Sensitivity Analysis 6.2	*Vehicle usage increases slower after 2004 (change rate 1/2 times)*

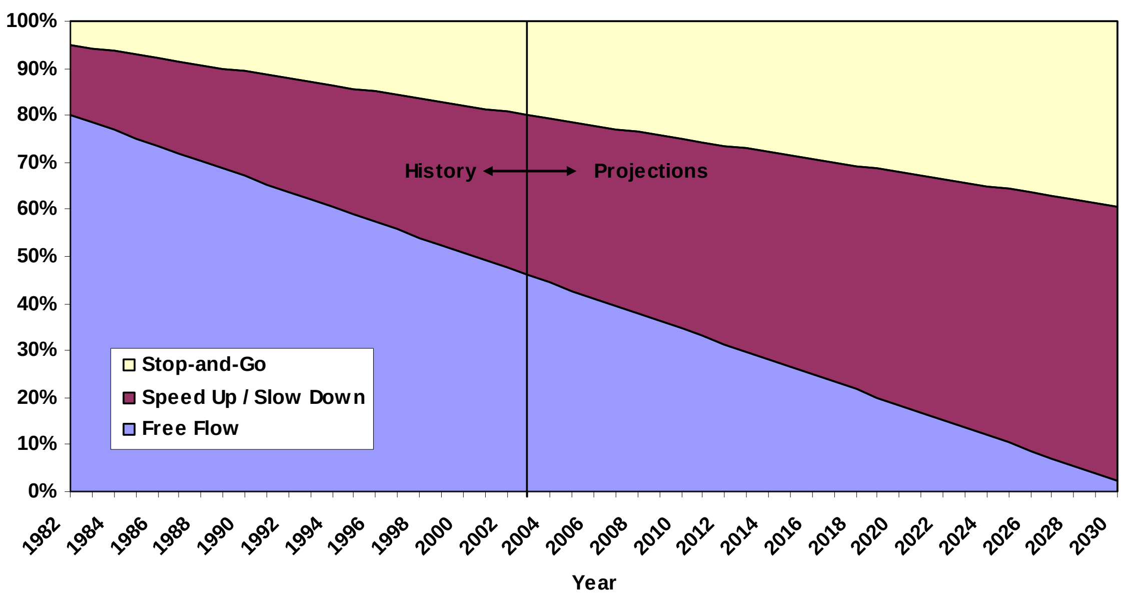

Figure 4-36: Percentage Composition of Congestion Levels (Reference Case: Worse)

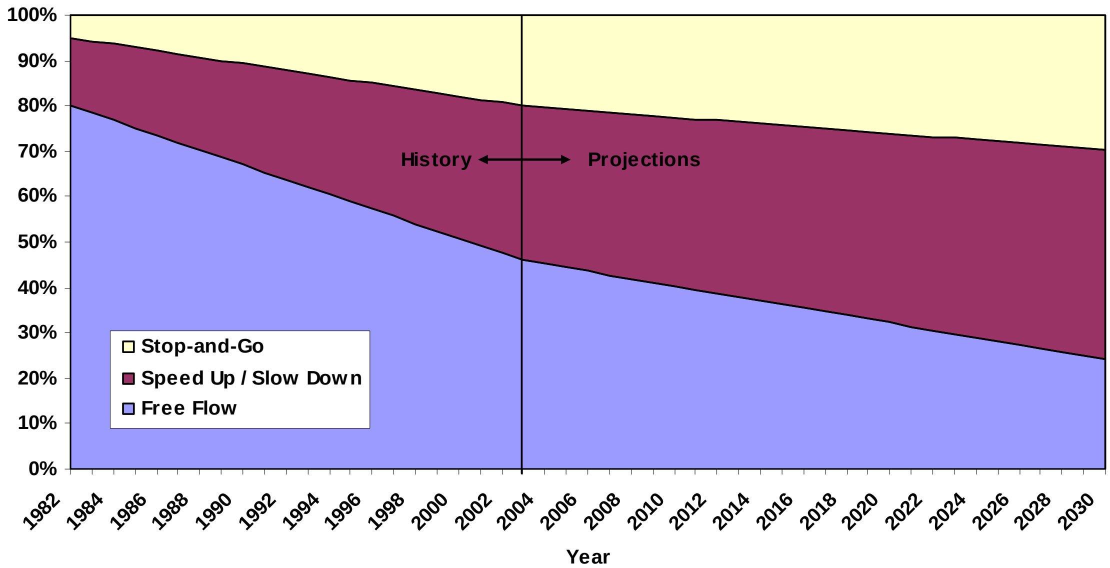

Figure 4-37: Percentage Composition of Congestion Levels (Sensitivity Analysis 3.1: Half Worse)

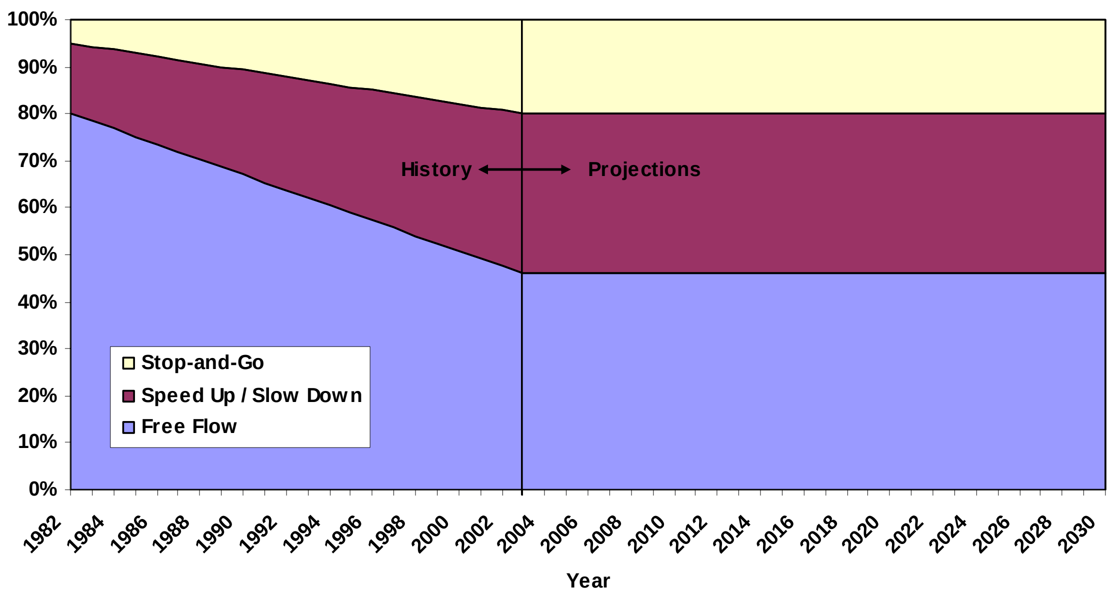

Figure 4-38: Percentage Composition of Congestion Levels (Sensitivity Analysis 3.2: Same with 2003)

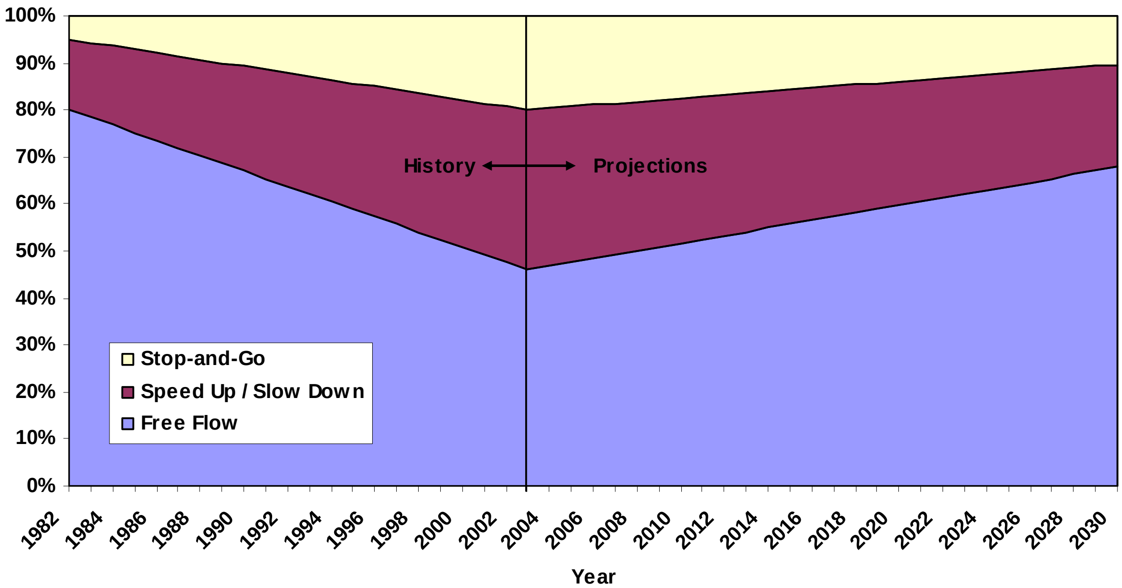

Figure 4-39: Percentage Composition of Congestion Levels (Sensitivity Analysis 3.3: Half Better)

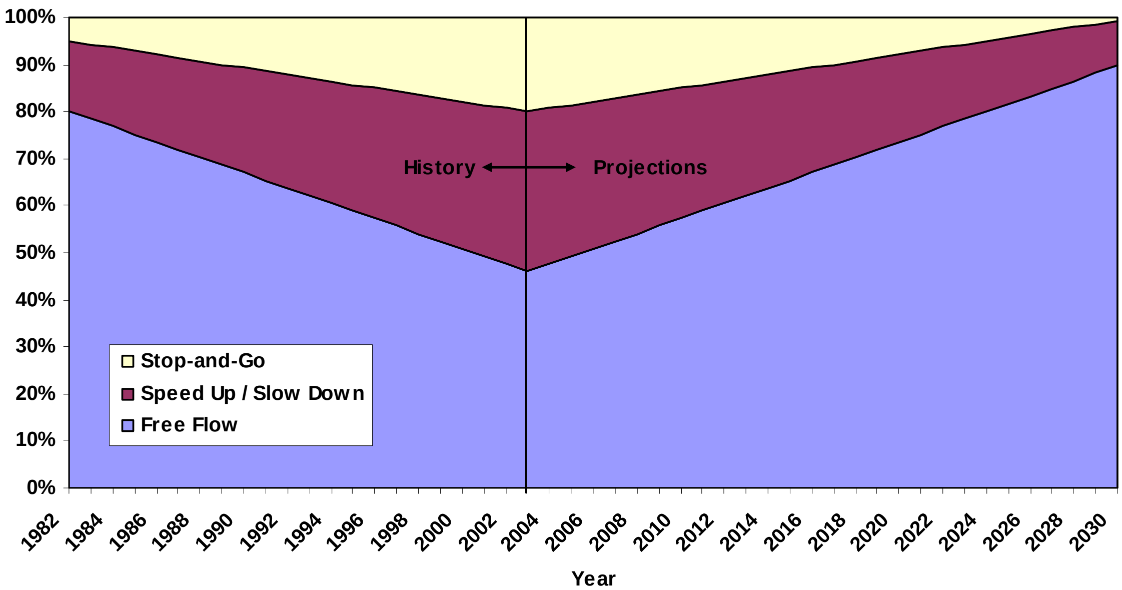

Figure 4-40: Percentage Composition of Congestion Levels (Sensitivity Analysis 3.4: Better)

Combining the above designing assumptions with the four models established before, the fuel consumption and emissions of the U.S. light-duty vehicle fleet in the 14 scenarios of sensitivity analysis can be calculated as those in the Reference Case (see Figures 4-41 ~ 4-45).

From these figures, two conclusions are made as below:

- The energy and environmental impacts of 14 scenarios are ranked in Table 4-9, where the Reference Case is taken as the baseline.
- According to the absolute values of these impacts, this thesis gets the importance order of different factors for the fleet fuel consumption and emissions (from high to low): congestion levels → new tech penetration → vehicle usage → SUV new sales → vehicle technology development → driving behavior. This order confirms the conclusion from impacts analysis that fleet population and traffic congestion are two most important factors for the fuel consumption and emissions of the U.S. light-duty vehicle fleet.

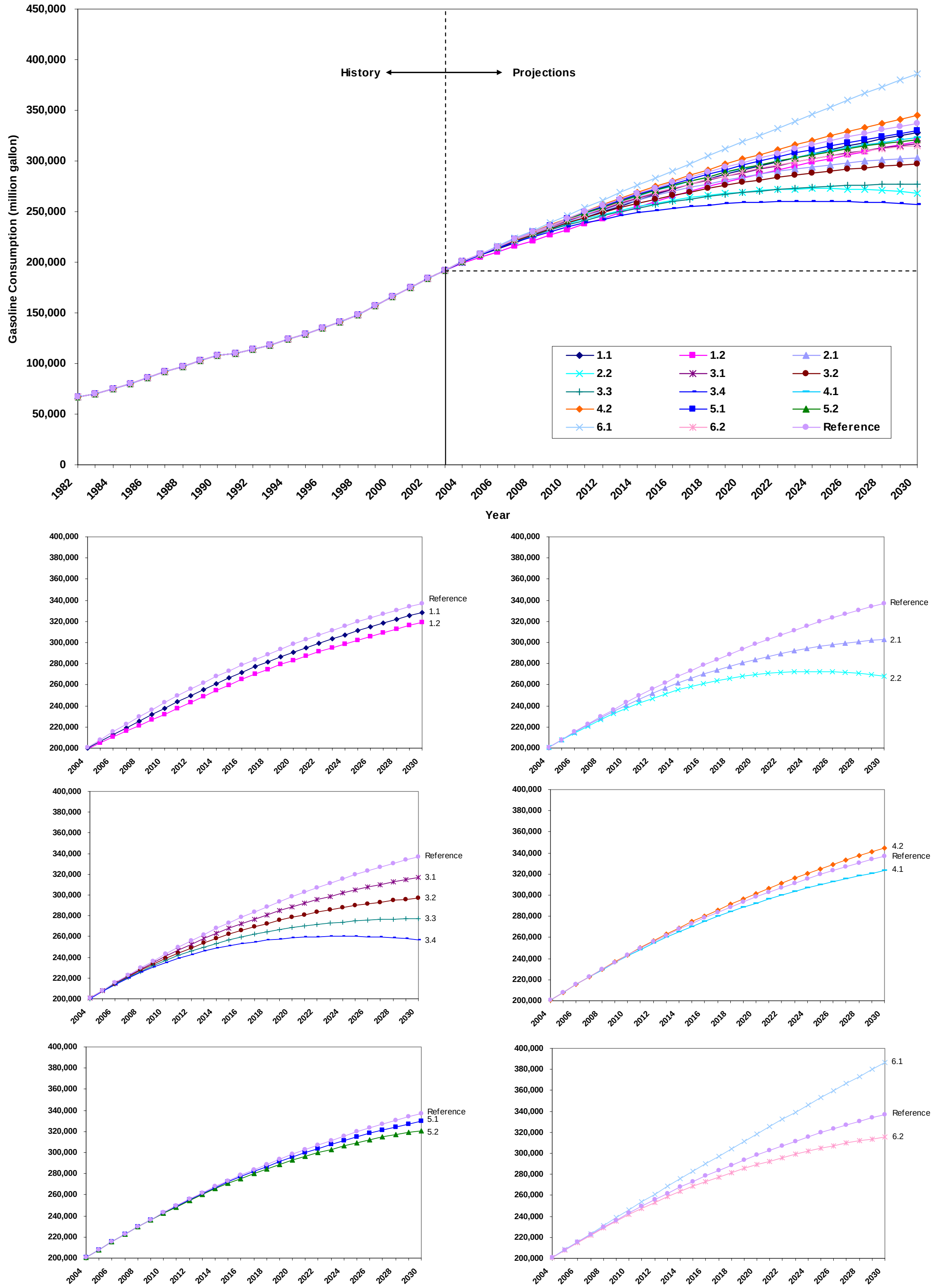

Figure 4-41: Sensitivity Analysis for Fuel Consumption

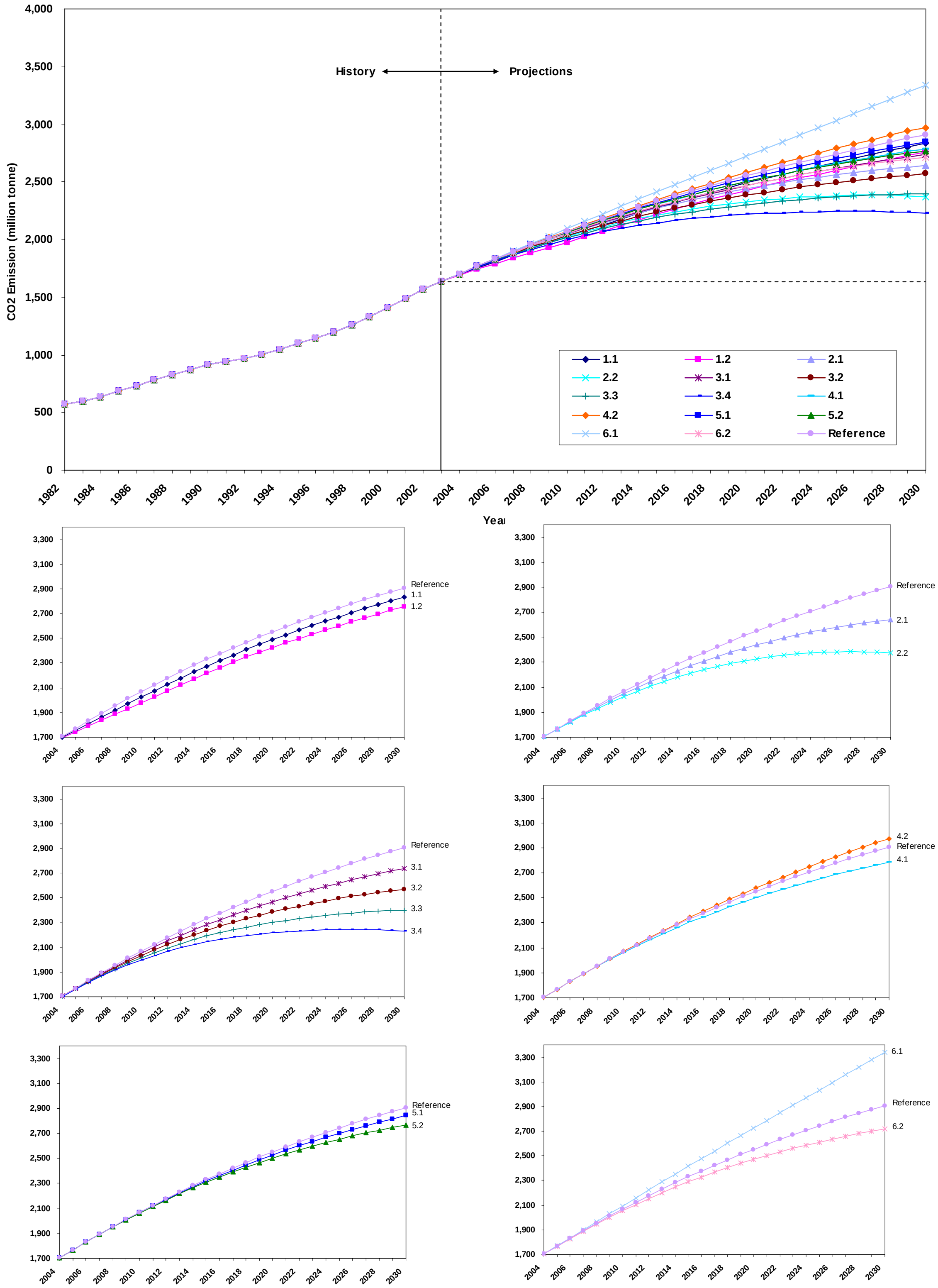

Figure 4-42: Sensitivity Analysis for CO_2 Emission

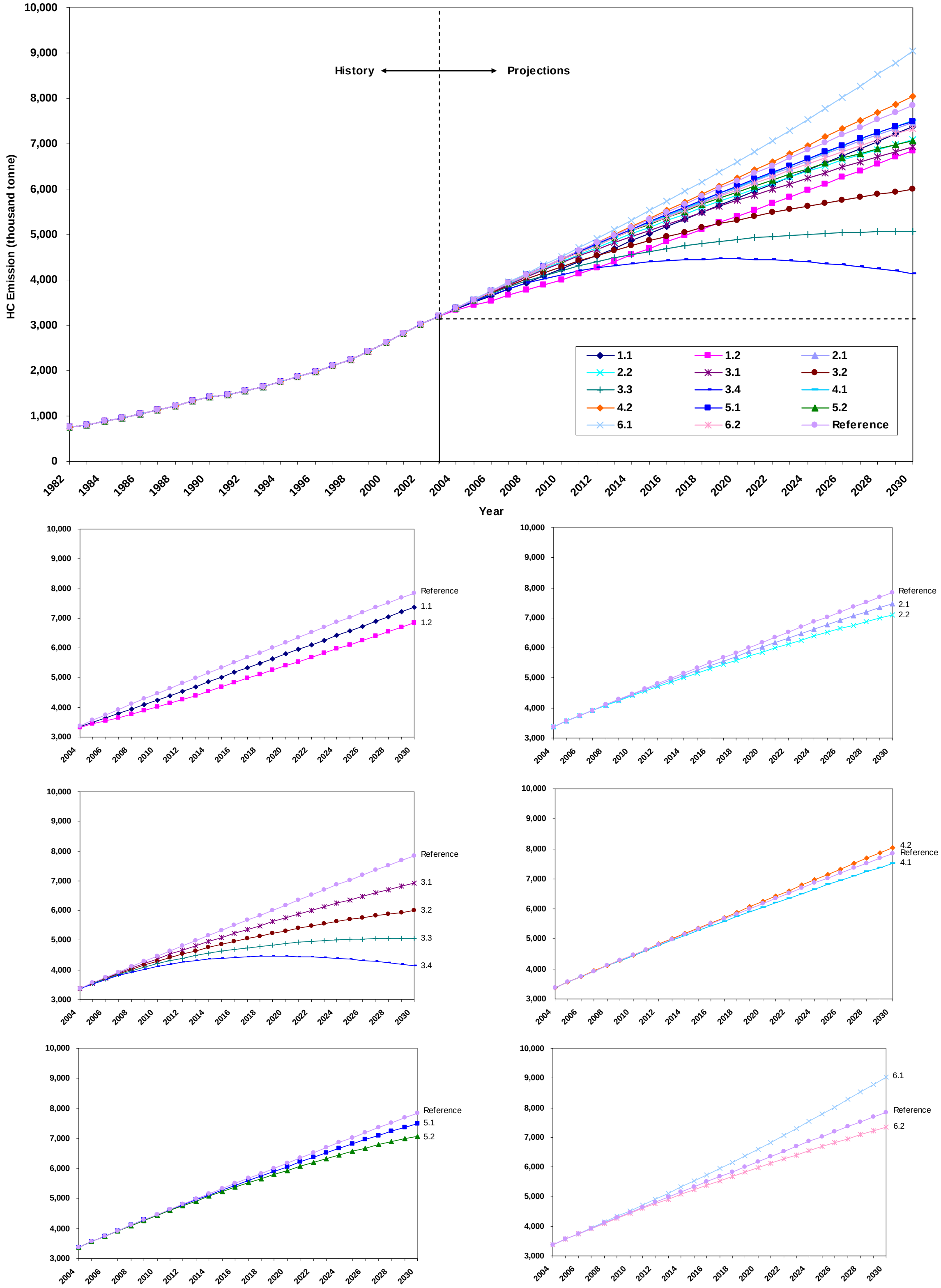

Figure 4-43: Sensitivity Analysis for HC Emission

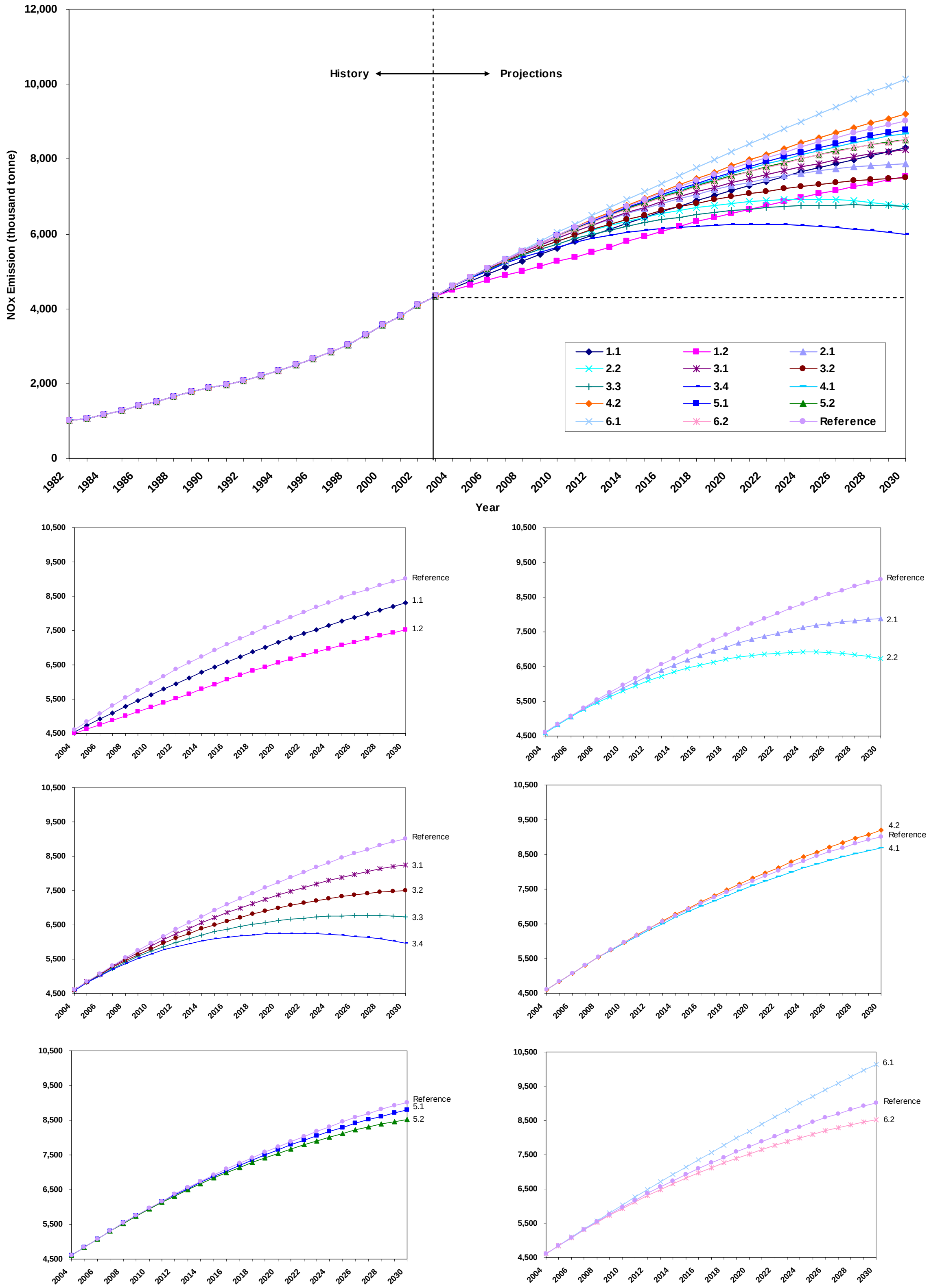

Figure 4-44: Sensitivity Analysis for NO_X Emission

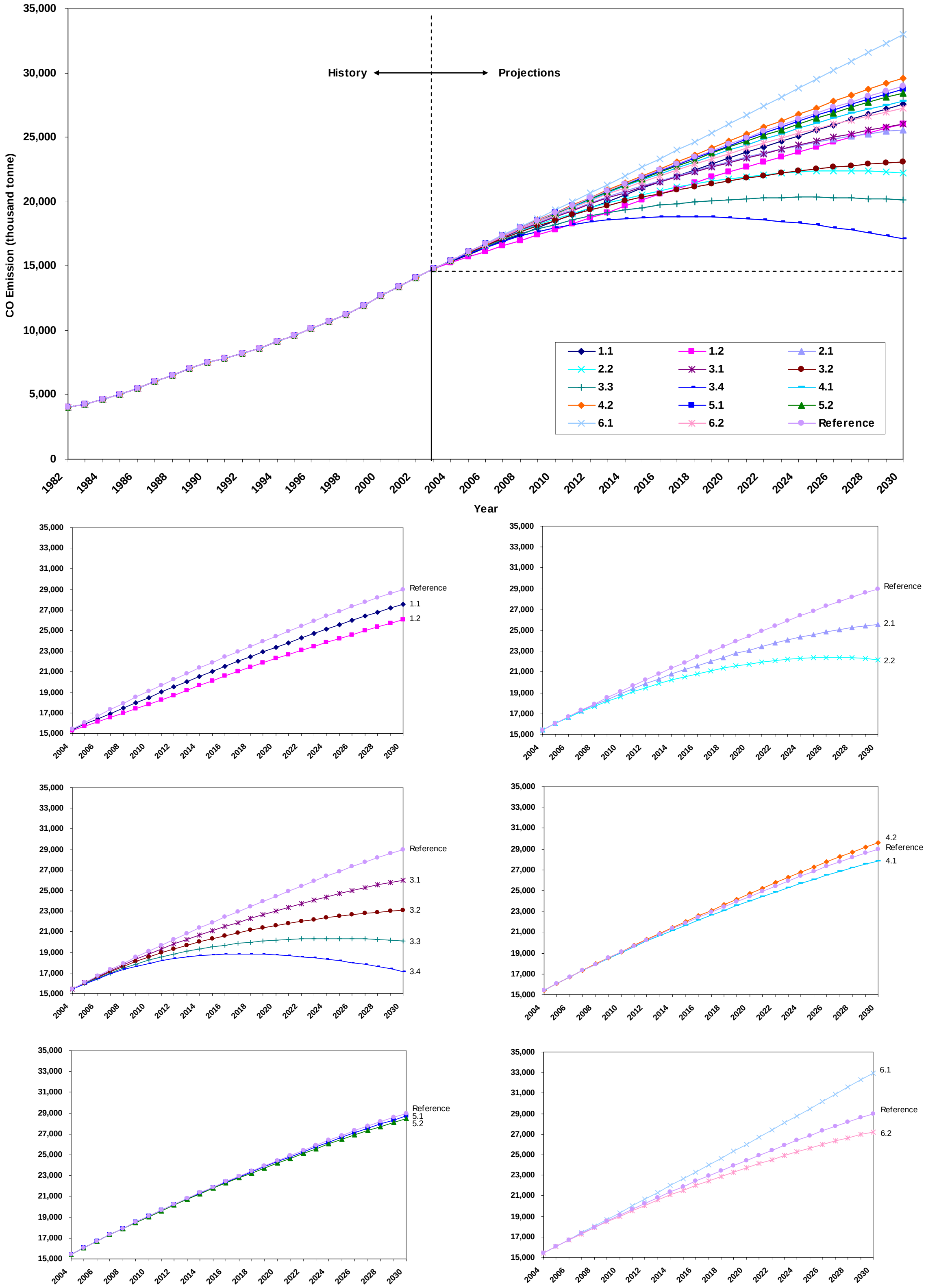

Figure 4-45: Sensitivity Analysis for CO Emission

Table 4-9: Impact Ranks for 14 Scenarios of Sensitivity Analysis (from Worst to Best)

Fuel Consumption:	*6.1 → 4.2 → Reference → 5.1 → 1.1 → 4.1 → 5.2 → 1.2 → 3.1 → 6.2 → 2.1 → 3.2 → 3.3 → 2.2 → 3.4*
CO_2 Emission:	*6.1 → 4.2 → Reference → 5.1 → 1.1 → 4.1 → 5.2 → 1.2 → 3.1 → 6.2 → 2.1 → 3.2 → 3.3 → 2.2 → 3.4*
HC Emission:	*6.1 → 4.2 → Reference → 4.1 → 5.1 → 2.1 → 1.1 → 6.2 → 2.2 → 5.2 → 3.1 → 1.2 → 3.2 → 3.3 → 3.4*
NO_x Emission:	*6.1 → 4.2 → Reference → 5.1 → 4.1 → 5.2 → 6.2 → 1.1 → 3.1 → 2.1 → 1.2 → 3.2 → 3.3 → 2.2 → 3.4*
CO Emission:	*6.1 → 4.2 → Reference → 5.1 → 5.2 → 4.1 → 1.1 → 6.2 → 1.2 → 3.1 → 2.1 → 3.2 → 2.2 → 3.3 → 3.4*

4.5 Offsetting the Impacts of Worsening Traffic

After getting the impacts of worsening traffic from 2004 to 2030, this section aims to find the best ways beyond transportation systems to offset the energy and environmental impacts of worsening traffic defined in the Reference Case. First, possible offset methods are designed in light of the results from impacts analysis and sensitivity analysis. Second, the feasibility and effectiveness of these methods are compared. And then, the economic implications and policy implications for these methods are also discussed.

4.5.1 Offset Analysis

The impact analysis and sensitivity analysis explore the important factors for the fleet fuel consumption and emission, and traffic congestion is one of such factors. Now, in order to offset the impacts of worsening traffic, changing other factors will naturally be the solution. In other words, possible offset methods should come from other important factors investigated by the impacts analysis and sensitivity analysis (see Table 4-10).

Table 4-10: Description of Offset Methods

BASELINE:	
Sensitivity Analysis 3.2	*Traffic congestion keeps the 2003 level from 2004-2030, i.e., percentage composition of congestion levels doesn't change after 2003.*
OFFSET METHODS:	
No. 1	*Increasing "New tech penetration" after 2004 (until the fleet fuel consumption and emissions close to the baseline levels);*
No. 2	*Decreasing "SUV new sales" after 2004 (until the fleet fuel consumption and emissions close to the baseline levels);*
No. 3	*Increasing "Vehicle tech development" after 2004 (until the fleet fuel consumption and emissions close to the baseline levels);*
No. 4	*Changing the above three factors after 2004 simultaneously (until the fleet fuel consumption and emissions close to the baseline levels);*
No. 5	*Decreasing "Vehicle usage" after 2004 (until the fleet fuel consumption and emissions close to the baseline levels);*
No. 6	*Improving "Driving behavior" after 2004 (until the fleet fuel consumption and emissions close to the baseline levels).*

Changing the above factor defined by each offset method, the fuel consumption and emissions of the U.S. light-duty vehicle fleet will also change. And when the fleet fuel consumption and emissions change to the levels in Sensitivity Analysis 3.2, which represents the "no-change" situation of traffic congestion from 2004-2030, the impacts of worsening traffic are offset by the corresponding method (see Figures 4-46 ~ 4-50). In another word, Sensitivity Analysis 3.2 provides the baseline for offset analysis. From Figures 4-46 ~ 4-50, several conclusions are made as below:

- *Offset Method 1:* When annual growth for new sales share of Hybrid equals 1.6%, the impacts of worsening traffic (fuel consumption and CO_2 mainly) can be offset by "new tech penetration". That is to say, the market share for Hybrid arrives at 29% in 2030, which is between the low penetration scenario (24% in 2030) and the medium penetration scenario (48% in 2030) in the LFEE report [Heywood et al., 2003].
- *Offset Method 2:* When new sales share of SUV is controlled between 1% and 5% in the future 27 years (this share in 2003 was 27%), the impacts of worsening traffic (fuel consumption and CO_2 mainly) can be offset by reduced "SUV new sales". That is to say, from 2004 to 2030, average annual new sales for SUV are around 0.5 million, much less than 4.9 million in 2003.
- *Offset Method 3:* When annual growth of fuel economy becomes 3 times more than the average annual growth in the past 20 years, the impacts of worsening

traffic (fuel consumption and CO_2 mainly) can be offset by "vehicle tech development". That is to say, from 2004 to 2030, the fuel economy for cars increases from 24.7 to 35.6 mpg, and the fuel economy for light trucks increases from 17.9 to 21.7 mpg.

- *Offset Method 4.1:* When annual growth for new sales share of Hybrid equals 1.5% and SUV annual new sales share decreases 10% (Sensitivity Analysis 2.1 + 1.1), the impacts of worsening traffic (fuel consumption and CO_2 mainly) can be offset. That is to say, Hybrid's market share arrives at 27% in 2030, new sales share of SUV is controlled between 10% and 20%, and vehicle technology development keeps the same trend in the past 20 years.
- *Offset Method 4.2:* When annual growth for new sales share of Hybrid equals 1.5% and annual growth for fuel economy becomes 2 times (Sensitivity Analysis 2.1 + 5.1), the impacts of worsening traffic (fuel consumption and CO_2 mainly) can be offset. That is to say, Hybrid's market share arrives at 27% in 2030, vehicle technology develops 2 times faster, and new sales share of SUV keeps the same trend in the past 20 years.
- *Offset Method 5:* When vehicle usage keeps the same level as that in 2004, the impacts of worsening traffic (fuel consumption and CO_2 mainly) can be offset by "vehicle usage". That is to say, vehicle usage doesn't change with time or people don't tend to drive more after 2004.
- *Offset Method 6:* When people tend to drive most aggressively under our speed assumption, the impacts of worsening traffic can be offset by "driving behavior". That is to say, for three road types, the percentage of Highway in annual mileage arrives at 100% after 2026.
- Compared to Offset Methods 2, 3, 5 and 6, Offset Method 1 would be more feasible to implement because the 29% market share for Hybrid in 2030 is close to the reasonable scenarios given by the LFEE report [Heywood et al., 2003],

while it is very difficult to decrease the annual new sales for SUV from 4.9 million to 0.5 million (Offset Method 2), to triple the annual growth of fuel economy (Offset Method 3), to keep the vehicle usage as same as the 2004 level (Offset Method 5), or to increase the Highway percentage in annual mileage to 100% after 2026 (Offset Method 6).

- Compared to Offset Methods 4.1 and 4.2, Offset Method 1 would be more effective on offsetting the impacts of worsening traffic because a slight increase in the annual new sales share of Hybrid (0.1%) can be equivalent to the rigid requirements for SUV new sales and vehicle technology development in Offset Methods 4.1 and 4.2.
- Therefore, based on Offset Method 1, promoting the market share of new vehicle technology (Hybrid mainly) is the most feasible and most effective method to offset the impacts of worsening traffic from 2004 to 2030.

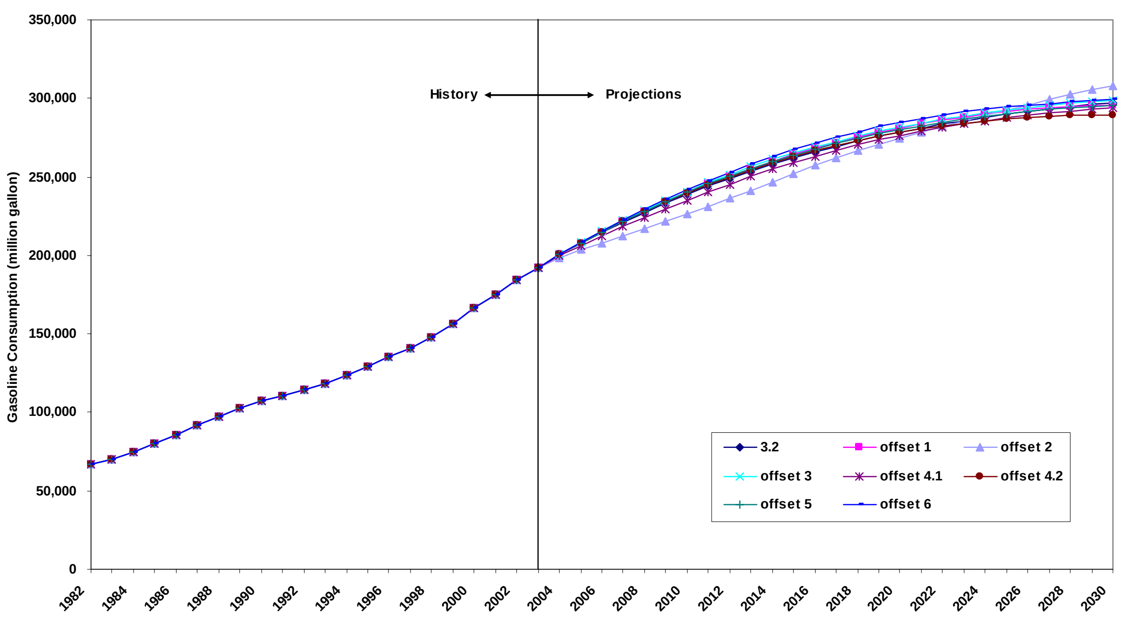

Figure 4-46: Offset Analysis for Fuel Consumption

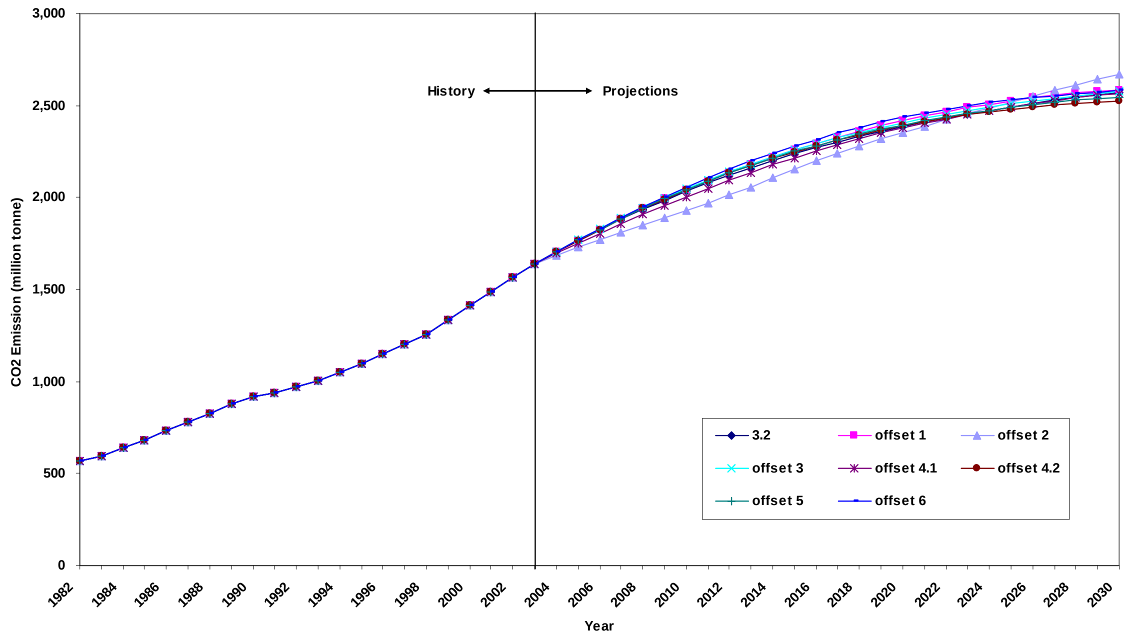

Figure 4-47: Offset Analysis for CO_2 Emission

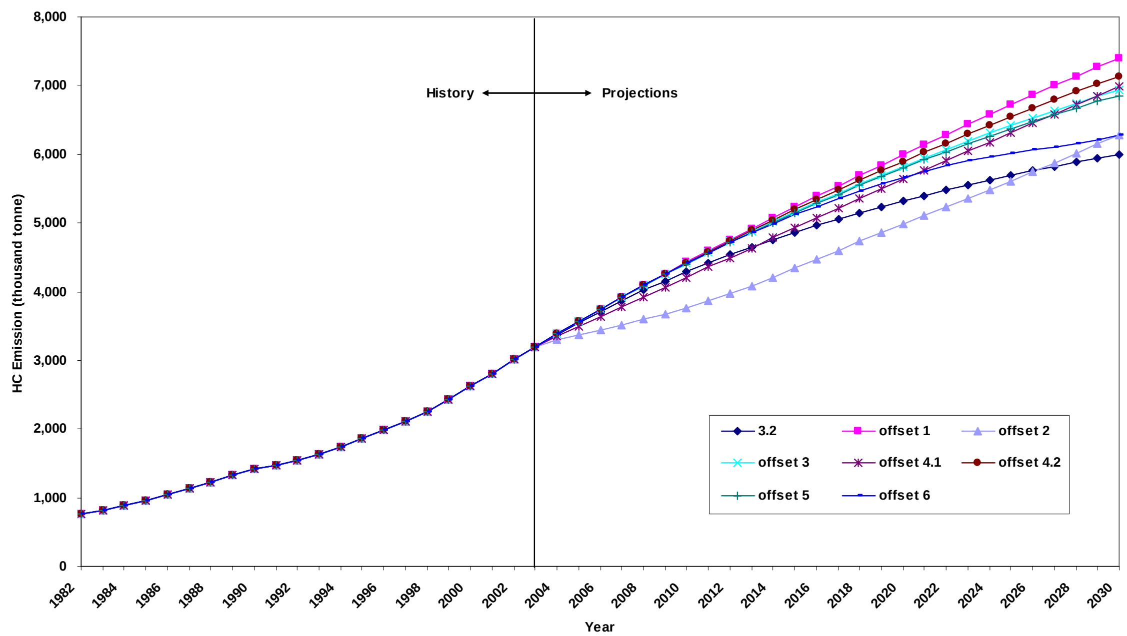

Figure 4-48: Offset Analysis for HC Emission

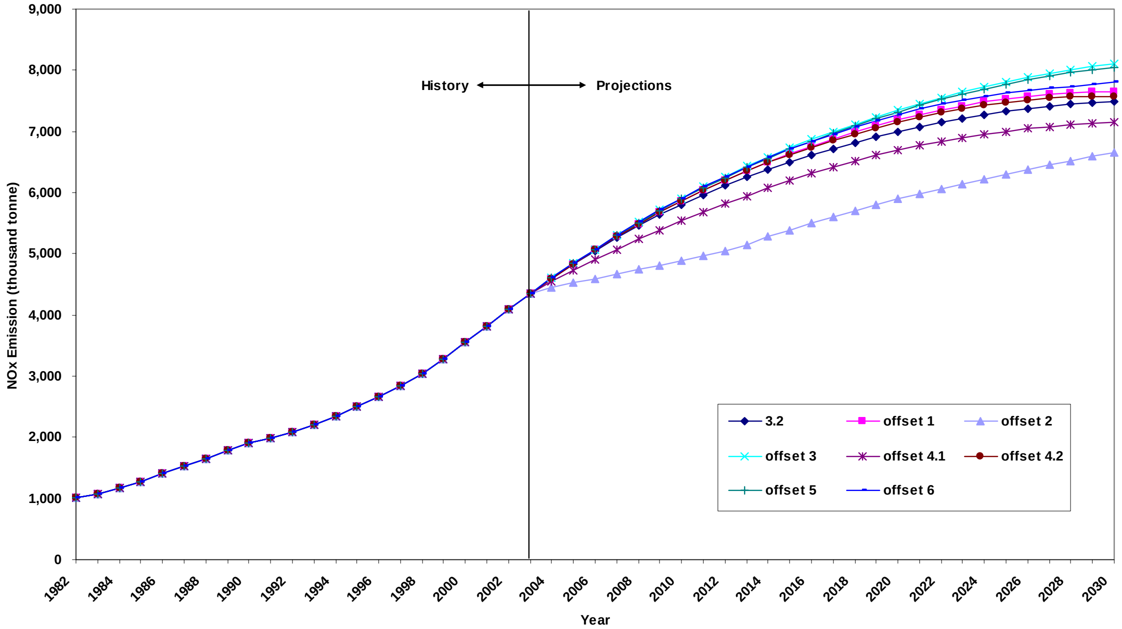

Figure 4-49: Offset Analysis for NO_X Emission

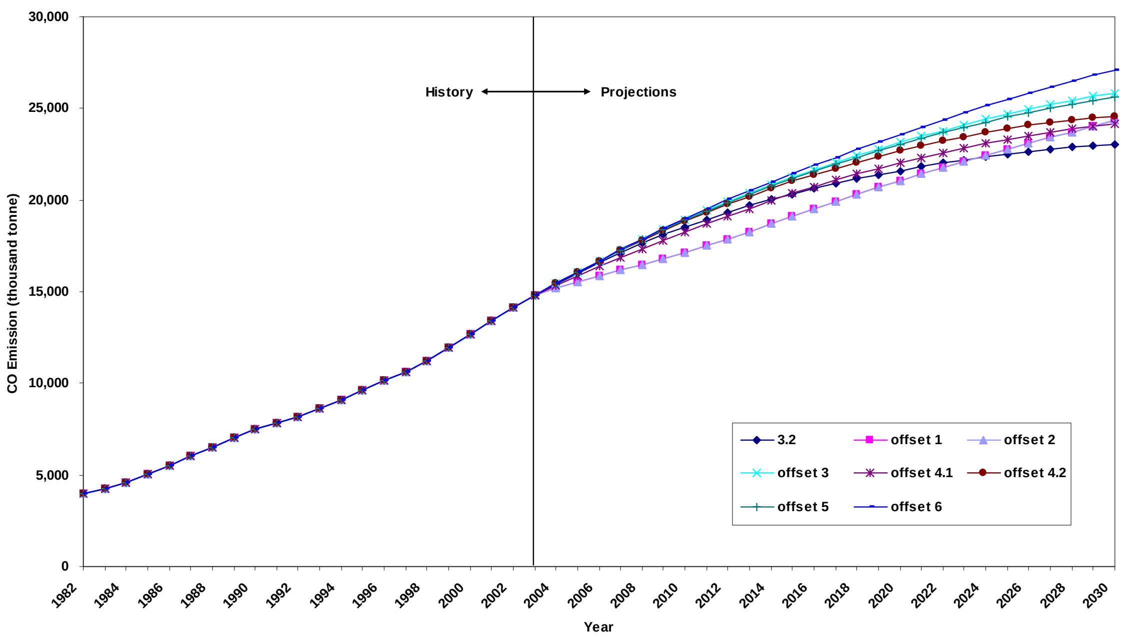

Figure 4-50: Offset Analysis for CO Emission

4.5.2 Additional Sensitivity Analysis

The above offset analysis concludes that promoting the market share of “Hybrid” is the most feasible and most effective method to offset the impacts of worsening traffic from 2004-2030. This part examines how this conclusion will change with different assumptions for worsening traffic in the Reference Case.

For simplicity, it is supposed that the future traffic congestion will become only half as bad (see Figure 4-51) when compared to the original assumptions (see Figure 4-14). Taking the similar steps with offset analysis, the results under new assumptions can be summarized in Table 4-11 and Figures 4-52 ~ 4-56.

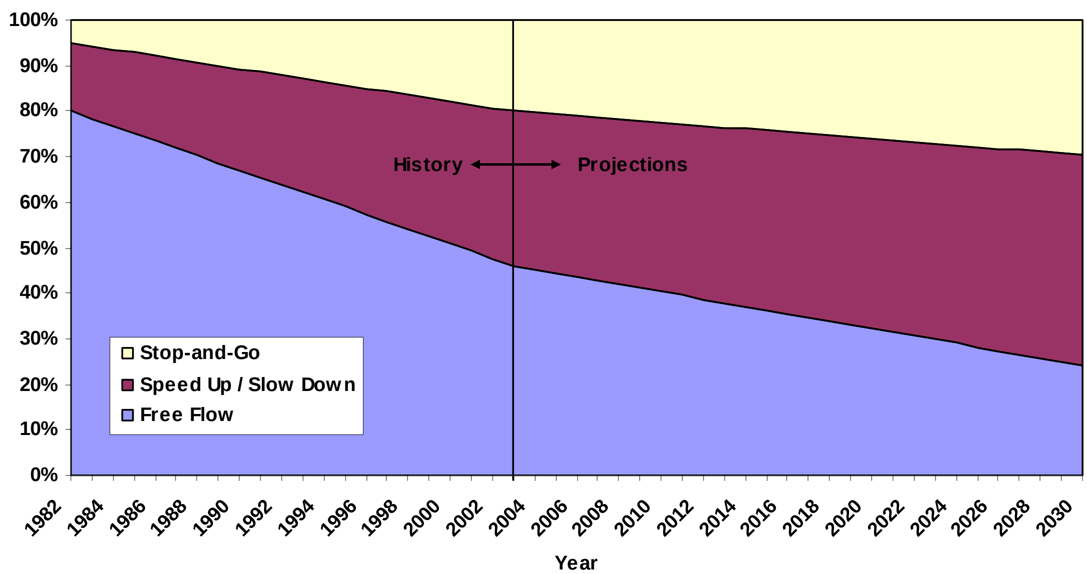

Figure 4-51: Half-Worst Traffic Congestion

Table 4-11: Comparison for Offset Methods under Different Traffic Assumptions

		Hybrid's market share in 2030	SUV's annual new sales 2004-2030	Cars' fuel economy in 2030	Light Trucks' fuel economy in 2030	Cars' mileage change 2004-2030	Light Trucks' mileage change 2004-2030	Highway% in annual mileage in 2030
REFERENCE CASE (No Offset)		***18%***	***4.9 million***	***27 mpg***	***19 mpg***	***1.2 % / year***	***0.6% / year***	***45%***
Offset Method 1	Worst Traffic	29%						
	Half-worst Traffic	24%						
Offset Method 2	Worst Traffic		0.5 million					
	Half-worst Traffic		1.3 million					
Offset Method 3	Worst Traffic			36 mpg	22 mpg			
	Half-worst Traffic			33 mpg	21 mpg			
Offset Method 4.1	Worst Traffic	27%	2.9 million					
	Half-worst Traffic	22%	3.3 million					
Offset Method 4.2	Worst Traffic	27%		30 mpg	20 mpg			
	Half-worst Traffic	20%		30 mpg	20 mpg			
Offset Method 5	Worst Traffic					0.0 % / year	0.0 % / year	
	Half-worst Traffic					0.6% / year	0.3% / year	
Offset Method 6	Worst Traffic							100%
	Half-worst Traffic							73%

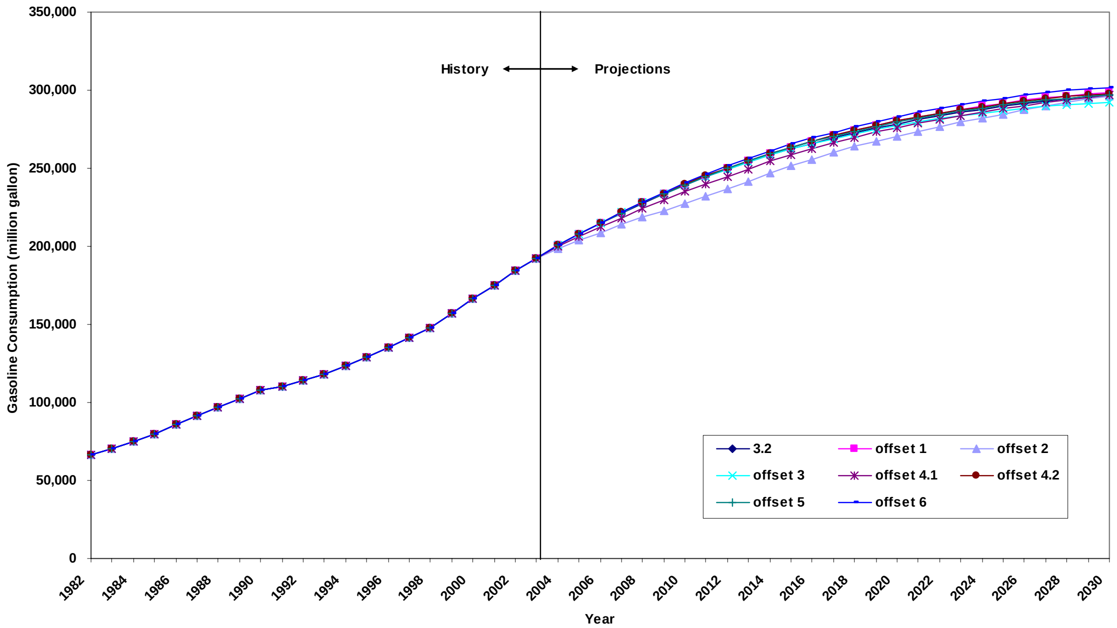

Figure 4-52: Additional Sensitivity Analysis for Fuel Consumption

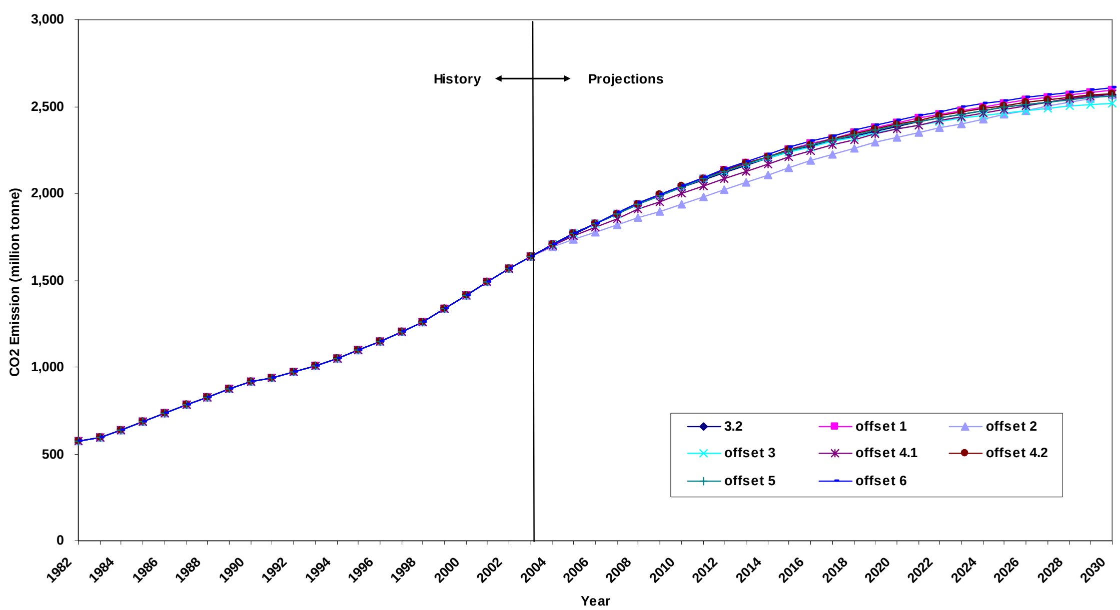

Figure 4-53: Additional Sensitivity Analysis for CO_2 Emission

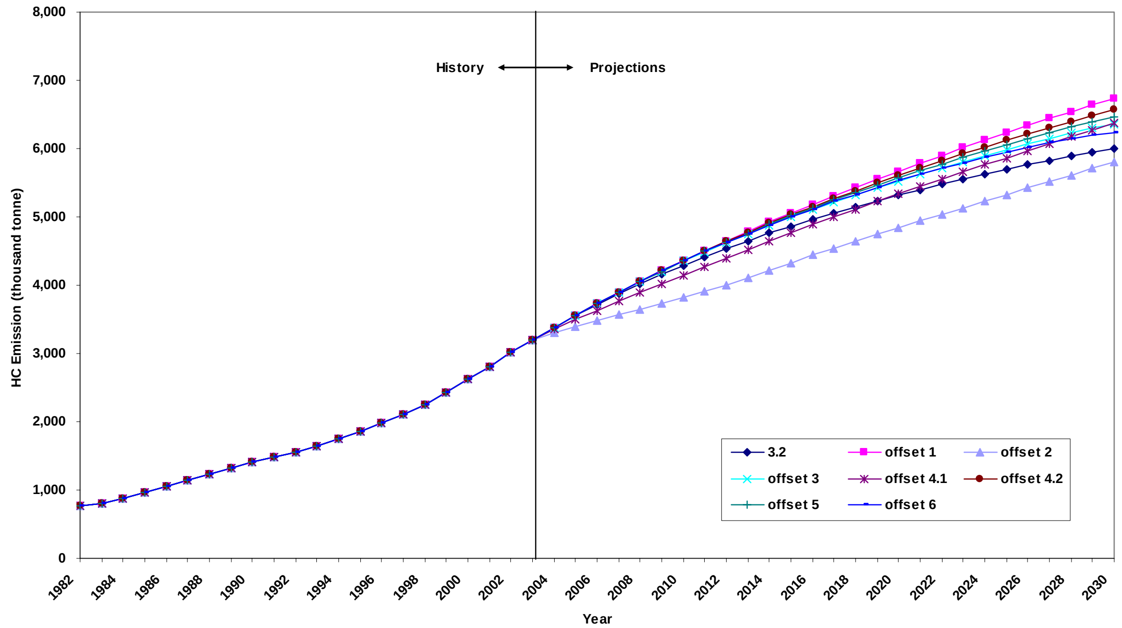

Figure 4-54: Additional Sensitivity Analysis for HC Emission

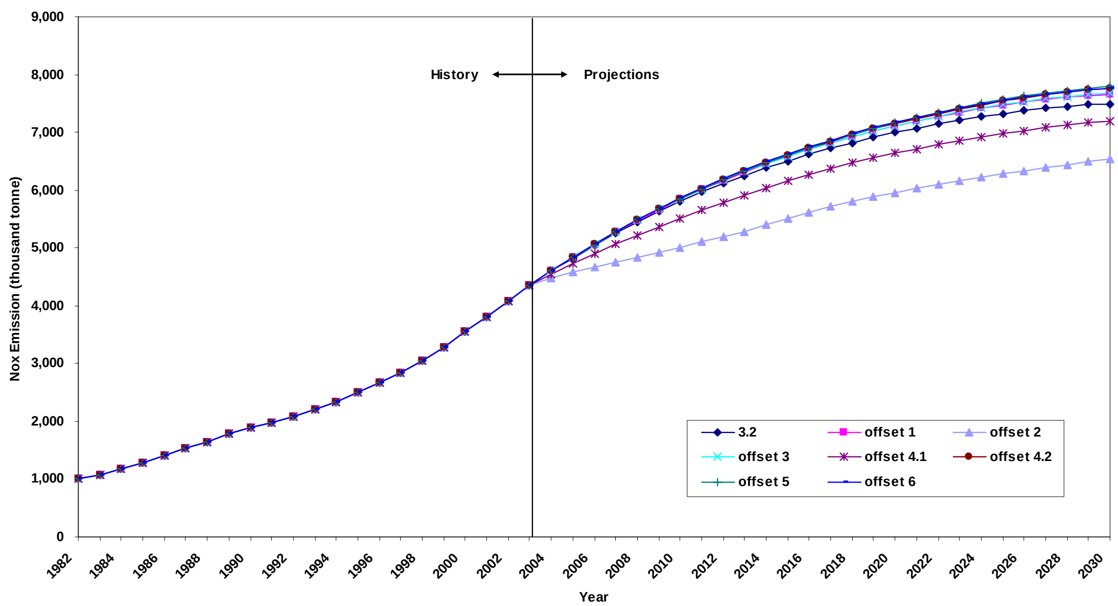

Figure 4-55: Additional Sensitivity Analysis for NO_X Emission

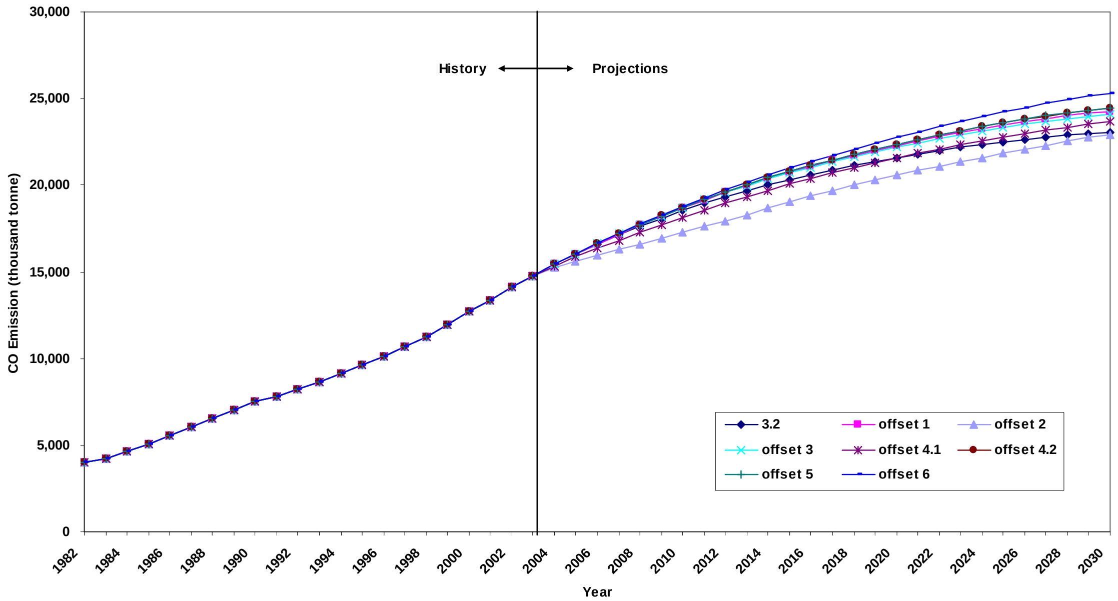

Figure 4-56: Additional Sensitivity Analysis for CO Emission

From Table 4-11 and Figures 4-52 ~ 4-56, several conclusions are made for the same offset methods when traffic congestion is not as bad:

- *Offset Method 1:* When annual growth for new sales share of Hybrid equals 1.3%, the impacts of worsening traffic (fuel consumption and CO_2 mainly) can be offset by "new tech penetration". That is to say, the market share for Hybrid arrives at 24% in 2030, which is comparative to the low penetration scenario (24% in 2030) in the LFEE report [Heywood et al., 2003].
- *Offset Method 2:* When new sales share of SUV is controlled between 5% and 9% in the future 27 years (this share in 2003 was 27%), the impacts of worsening traffic (fuel consumption and CO_2 mainly) can be offset by reduced "SUV new sales". That is to say, from 2004 to 2030, average annual new sales for SUV are around 1.3 million, much less than 4.9 million in 2003.
- *Offset Method 3:* When annual growth for fuel economy becomes 2 times more than the average annual growth in the past 20 years, the impacts of worsening

traffic (fuel consumption and CO_2 mainly) can be offset by "vehicle tech development". That is to say, from 2004 to 2030, the fuel economy for cars increases from 24.7 to 32.9 mpg, and the fuel economy for light trucks increases from 17.9 to 20.8 mpg.

- *Offset Method 4.1:* When annual growth for new sales share of Hybrid equals 1.2% and SUV annual new sales share decreases 10% (Sensitivity Analysis 2.1 + 1.1), the impacts of worsening traffic (fuel consumption and CO_2 mainly) can be offset. That is to say, Hybrid's market share arrives at 22% in 2030, new sales share of SUV is controlled between 10% and 20%, and vehicle technology development keeps the same trend in the past 20 years.
- *Offset Method 4.2:* When annual growth for new sales share of Hybrid equals 1.1% and annual growth for fuel economy becomes 2 times (Sensitivity Analysis 2.1 + 5.1), the impacts of worsening traffic (fuel consumption and CO_2 mainly) can be offset. That is to say, Hybrid's market share arrives at 20% in 2030, vehicle technology develops 2 times faster, and new sales share of SUV keeps the same trend in the past 20 years.
- *Offset Method 5:* When vehicle usage increases 1/2 time as fast as the historical average rate, the impacts of worsening traffic (fuel consumption and CO_2 mainly) can be offset by "vehicle usage". That is to say, from 2004 to 2030, annual mileage for passenger cars and light trucks increase 0.6% and 0.3% per year respectively (these two numbers were 1.2% and 0.6% in the past 20 years).
- *Offset Method 6:* When people tend to drive more aggressively under our speed assumption, the impacts of worsening traffic can be offset by "driving behavior". That is to say, for three road types, the percentage of Highway in annual mileage arrives at 73% by the end of 2030.
- From the above changes in offset methods (see Table 4-11), it is concluded that when the assumptions for worsening traffic are less strict, more options become

feasible to offset the impacts of worsening traffic. **However, the following economic and policy implications analyses are still based on the original assumptions for worsening traffic.**

4.5.3 Economic Implications

Because of the excellent fuel economy and environmental performance of Hybrid compared to other vehicle types especially SUV, the fuel consumption and emissions of the U.S. light-duty vehicle fleet will decrease with the growth of Hybrid population. When the fuel consumption and emissions saved by increasing Hybrid are quantitatively equal those caused by worsening traffic, the energy and environmental impacts of worsening traffic can be treated as offset. The above offset analysis have pointed out that promoting the market share of Hybrid (Offset Method 1) is the most feasible and most effective method to offset the impacts of worsening traffic, and this part will explore the economic implications of such a method. In other words, the fuel consumption and emissions saved by Offset Method 1 on the basis of Reference Case will be converted into numerical economic benefits, which are also the measure for economic costs of worsening traffic.

Obviously, obtaining the appropriate unit prices for automotive fuel and pollutant emissions is the first step. This thesis only considers fuel consumption and CO_2 emissions for the enhanced concern on energy crisis and global warming. And all kinds of fuel are unified into the gasoline.

The gasoline prices during 2004-2030 come from the reference case, high price case and low price case in the Annual Energy Outlook 2006 [EIA, 2005] (see Figure 4-57). Here the prices for gasoline are the sales weighted prices for all grades including Federal, State and local taxes.

The carbon prices during 2004-2030 come from the "RICE" model (regional integrated model of climate and the economy) with linear interpolation and extrapolation [Nordhaus, 2001] (see Figure 4-58). Here the carbon prices, also known as carbon taxes, are the market prices and marginal costs of reducing CO_2 emissions. Under different circumstances, carbon prices vary so much and this model discusses three representative scenarios: "Kyoto Protocol without U.S.A." (the current situation), "Original Kyoto Protocol" (with U.S. participation), and "Economically Efficient Policy" (balancing estimated costs and benefits of emissions reductions). Each scenario assumes full trading and therefore there is no difference between the carbon prices in different countries. In addition, from Figure 4-58, it is obvious the carbon prices in Europe and other countries fall dramatically with the U.S. out of the picture.

For the purpose of comparison, this thesis supposes an annual inflation rate of 5% and converts all the above prices into the 2004 values.

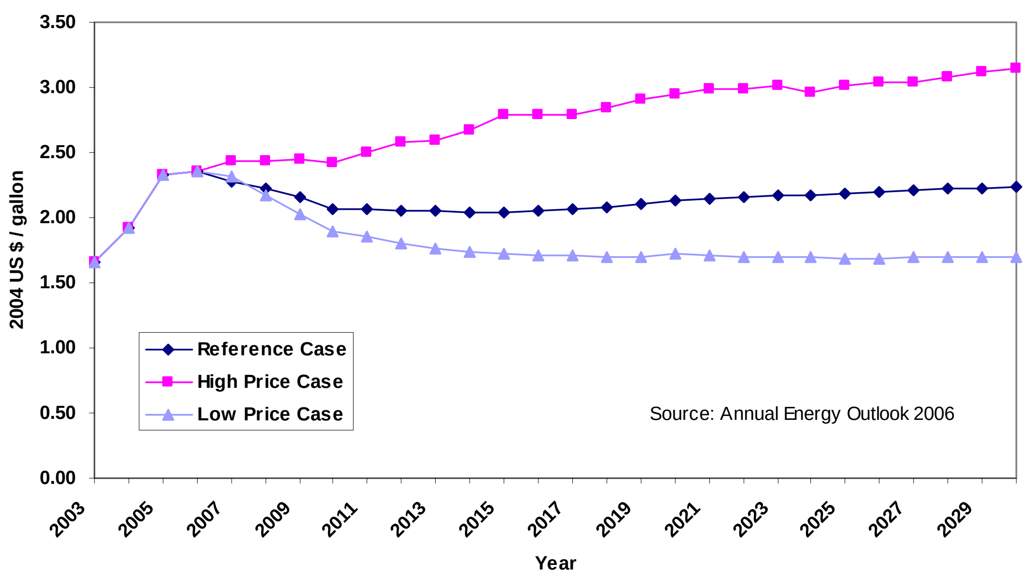

Figure 4-57: Gasoline Prices

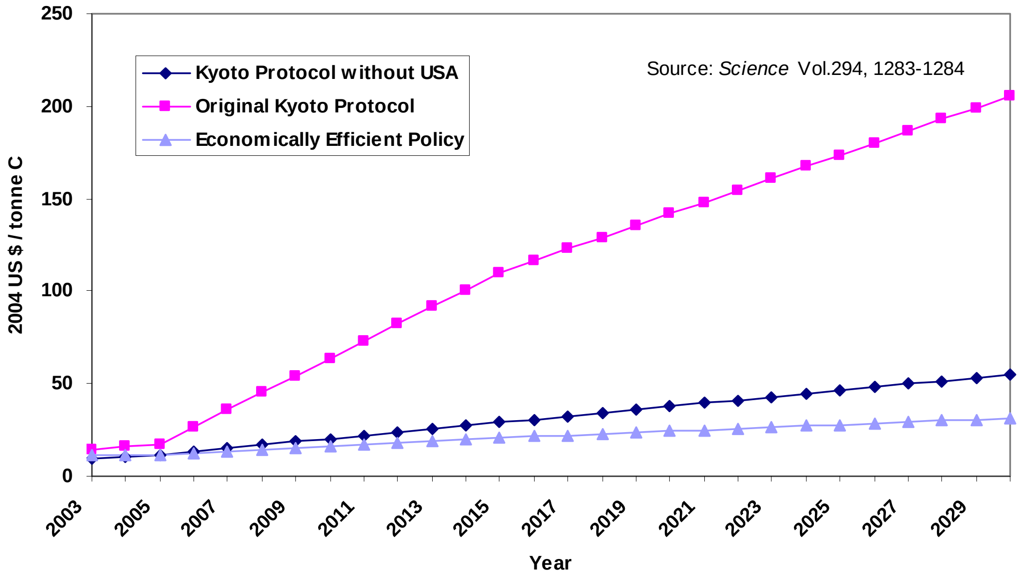

Figure 4-58: Carbon Prices

With the unit prices for gasoline and CO_2, as well as the fleet fuel consumption and CO_2 emissions in Offset Method 1 and the Reference Case calculated before, the total economic benefits from gasoline and carbon savings can be easily investigated (see Formula 4-1). Because both gasoline prices and carbon prices have three different cases, there should be nine scenarios for the total economic benefits ($C_3^1 \times C_3^1 = 9$, see Figure 4-59). Moreover, the percentage composition of total economic benefits in 2030 and the relevant "iso-benefits" curves are also developed in this thesis (see Figures 4-60 and 4-61).

$$TotalEconomicBenefits = Gasoline\Pr ice \times GasolineSavings + Carbon\Pr ice \times CarbonSavings \quad (4\text{-}1)$$

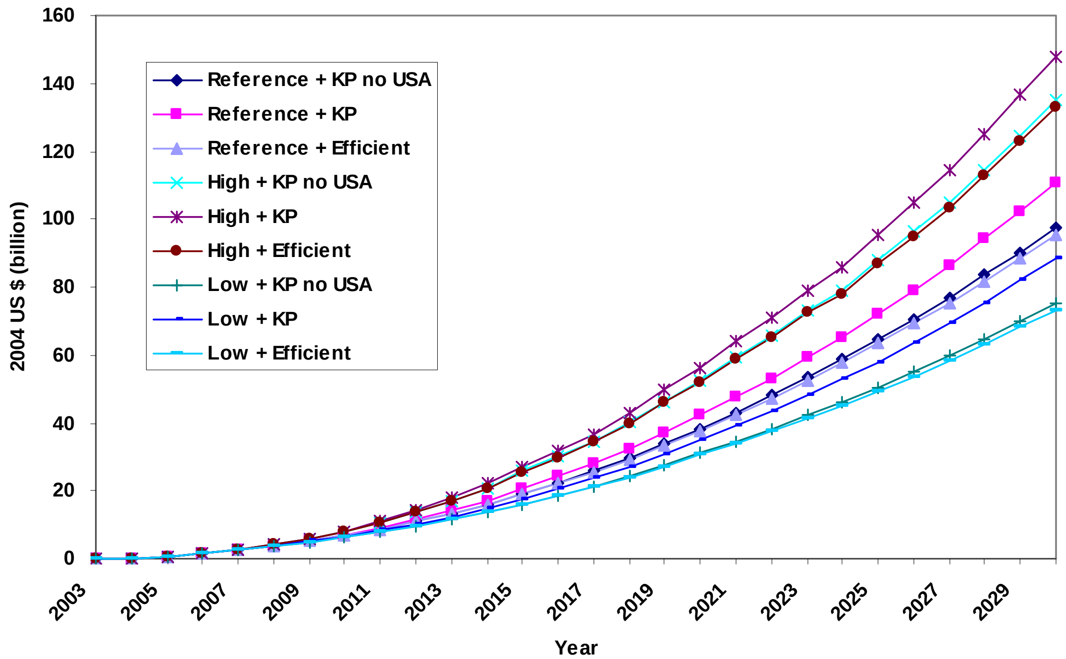

Figure 4-59: Total Benefits from Gasoline and Carbon Savings (by Offset Method 1)

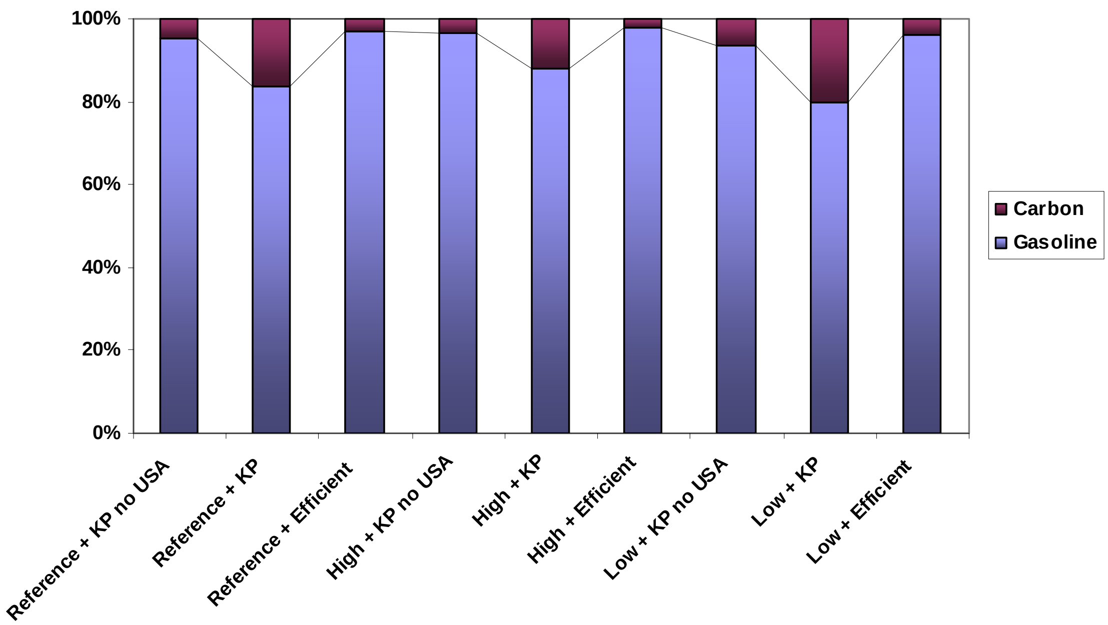

Figure 4-60: Percentage Composition of Total Benefits in 2030 (by Offset Method 1)

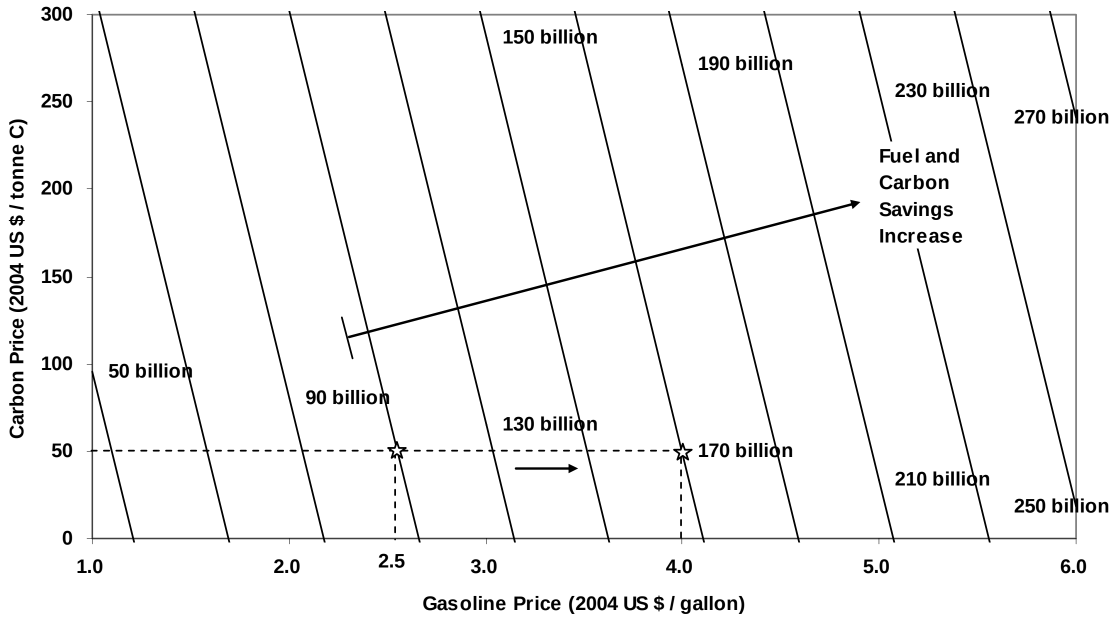

Figure 4-61: "Iso-Benefits" Curves in 2030 (2004 US $, by Offset Method 1)

From Figures 4-59 ~ 4-61, several conclusions are made as below:

- For Offset Method 1, the total economic benefits from gasoline and carbon savings increase fast with time goes by (see Figure 4-59). Specifically, the total benefits in 2030 range from 73 to 148 billion US dollars (2004 value).
- For all the nine scenarios, most of total economic benefits come from gasoline savings while carbon savings only account for a small portion (see Figure 4-60).
- For the total economic benefits in a specific year, because the gasoline savings and carbon tax savings have been decided by Offset Method 1 and the Reference Case, the total benefits only vary with gasoline price and carbon price, which can be described by the "iso-benefits" curves (see Formula 4-1 and Figure 4-61). In light of the slope of all these curves, it is demonstrated that the total benefits are more sensitive to the change of gasoline price than that of carbon price.
- As mentioned before, the economic benefits from Offset Method 1 (more

Hybrids) are also the measure for economic costs of worsening traffic. Based on that, many meaningful calculations can be done with the "iso-benefits" curves (see Figure 4-61, 2004 US $). For example, when the gasoline and carbon prices are 2.5 $ / gallon and 50 $ / tonne C respectively in 2030, the economic benefits from Offset Method 1 will be around $ 90 billion and each Hybrid will contribute $ 1406 to offset the energy and environmental impacts of worsening traffic in that year (2030 Hybrid population is 64 million in the Reference Case). On the other hand, the economic costs of worsening traffic are also $ 90 billion and each light-duty vehicle bears $ 258 from the energy and environmental impacts of worsening traffic (2030 light-duty vehicle fleet population is 349 million in the Reference Case). Furthermore, if the gasoline price goes up from 2.5 $ / gallon to 4.0 $ / gallon in 2030, the economic benefits from Offset Method 1 or the economic costs of worsening traffic will rise to around $ 170 billion. In another word, the economic benefits contributed by each Hybrid will increase $ 1250, while the economic costs borne by each light-duty vehicle will increase $ 229.

- The above economic calculations provide useful reference for policy makers to subsidize the market penetration of Hybrid. In future study, these results can also be applied in cost / benefit analysis for comparison between the offset methods beyond transportation systems and other methods intending to improve traffic congestion directly within transportation systems.

4.5.4 Policy Implications

After modeling, impact analysis and offsetting analysis, this thesis concludes that promoting the market share of Hybrid is the most feasible and most effective method among the options analyzed to "offset" the impacts of worsening traffic on the light-duty vehicle fleet fuel consumption and emissions from 2004-2030. This conclusion happens to have the same view with the Bush Administration, which advocates reducing America's dependence on imported petroleum through developing new vehicles powered by alternative fuels, such as Hybrid, EV and FCV (see the Advanced Energy Initiative, January 31, 2006). Specifically, President Bush plans to displace an amount of petroleum imports equivalent to 75% of what America is expected to import from the Middle East in 2025. In this part, the feasibility of such an objective will be investigated.

First, the estimated amounts of petroleum imports from the Middle East can be found in the Annual Energy Outlook 2006 [EIA, 2005]. Further, the amounts of Mideast petroleum consumed in the transportation sector and in the light-duty vehicle fleet can also be identified with the assumption that the transportation sector accounts for 67% of the U.S. petroleum consumption and the light-duty vehicle fleet accounts for 58% of the transportation petroleum consumption [EIA, 2005] (see Figure 4-62). In 2025, the U.S. will import 34,952 million gallons petroleum from the Middle East. Among such an import amount, 23,418 million gallons petroleum goes to the transportation sector and the light-duty vehicle fleet consumes 13,583 million gallons.

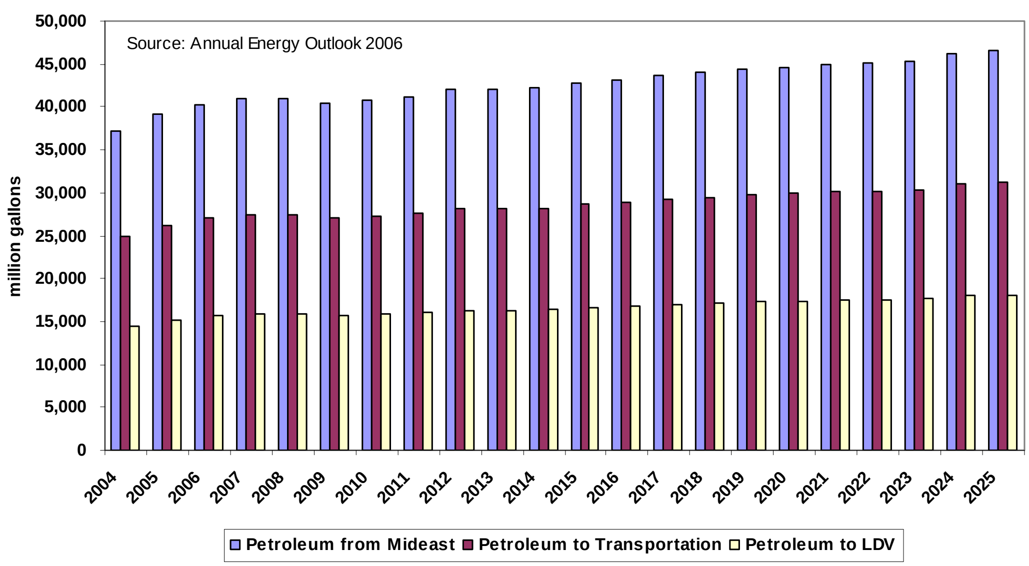

Figure 4-62: The U.S. Petroleum Imports from the Middle East

Next, the petroleum savings from Hybrid, EV and FCV can be developed with the four models for fleet population, vehicle technology, driving behavior and traffic congestion in this thesis. For simplicity, it is assumed that Hybrid is fueled by electricity (Plug-in Hybrid) and all the electricity consumed by Hybrid and EV comes from non-petroleum sources. Furthermore, the petroleum savings will change with different scenarios for market penetration of new vehicle technologies. Here three penetration scenarios are considered: Scenario 1, the market penetration of Hybrid, EV and FCV are 0.5 time as fast as the Reference Case; Scenario 2, the market penetration of Hybrid, EV and FCV are the same as the Reference Case; and Scenario 3, the market penetration of Hybrid, EV and FCV are 1.5 times as fast as the Reference Case (see Figures 4-63, 4-65 and 4-67). Finally, the petroleum savings under these three scenarios are calculated (see Figures 4-64, 4-66 and 4-68).

From Figures 4-63 ~ 4-68, several conclusions are made as below:

- For Scenario 1 (the 2025 market shares of Hybrid, EV and FCV are 8%, 1% and 1% respectively), the petroleum savings in 2025 will be equivalent to the Mideast petroleum consumed by the light-duty vehicle fleet in that year.
- For Scenario 2 (the 2025 market shares of Hybrid, EV and FCV are 13%, 3% and 1% respectively), the petroleum savings in 2025 will be equivalent to the Mideast petroleum consumed by the whole transportation sector in that year.
- For Scenario 3 (the 2025 market shares of Hybrid, EV and FCV are 20%, 4%, 2% respectively), the petroleum savings in 2025 will be equivalent to the total petroleum imported from the Middle East in that year.
- From the above analyses, it is concluded that President Bush's objective for petroleum imports reduction is feasible with the successful penetration of new vehicle technologies powered by alternative fuels.

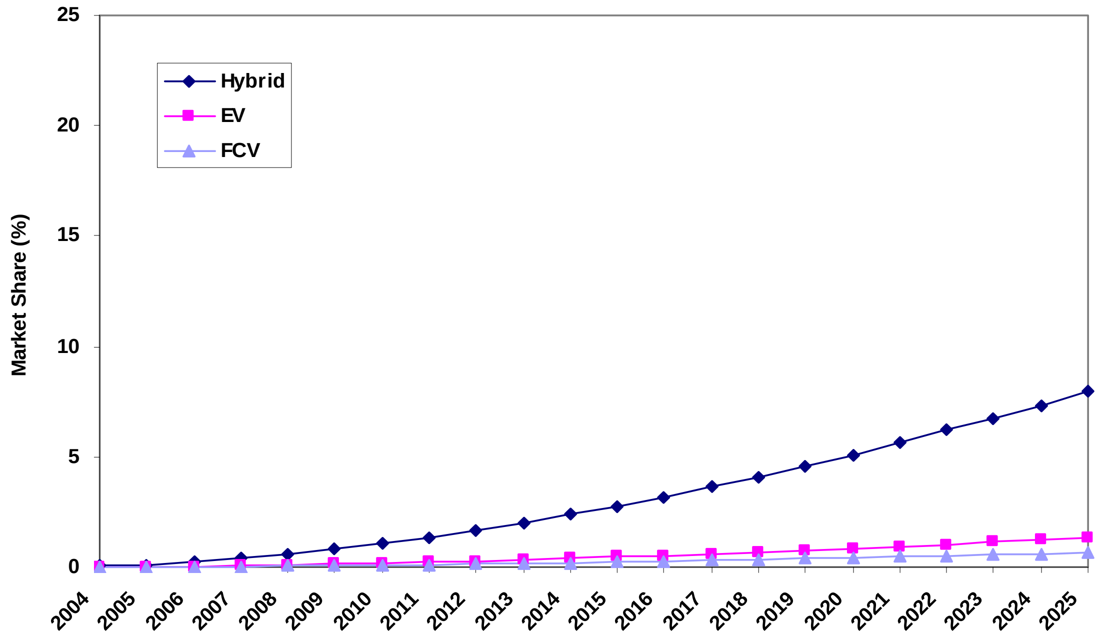

Figure 4-63: Market Penetration of New Vehicle Technologies (Scenario 1)

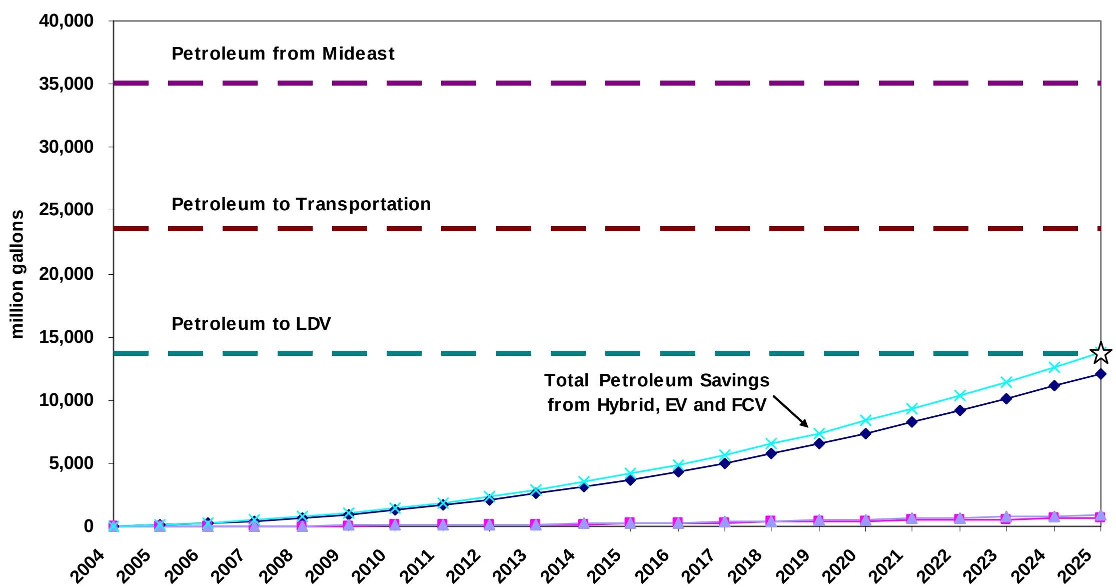

Figure 4-64: Petroleum Savings from New Vehicle Technologies (Scenario 1)

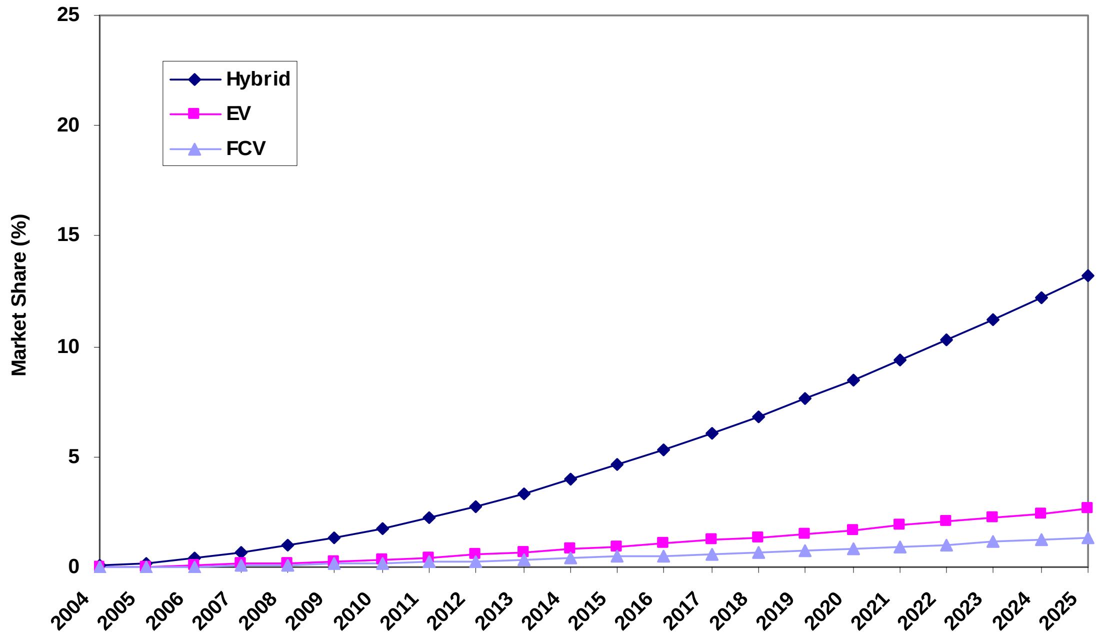

Figure 4-65: Market Penetration of New Vehicle Technologies (Scenario 2)

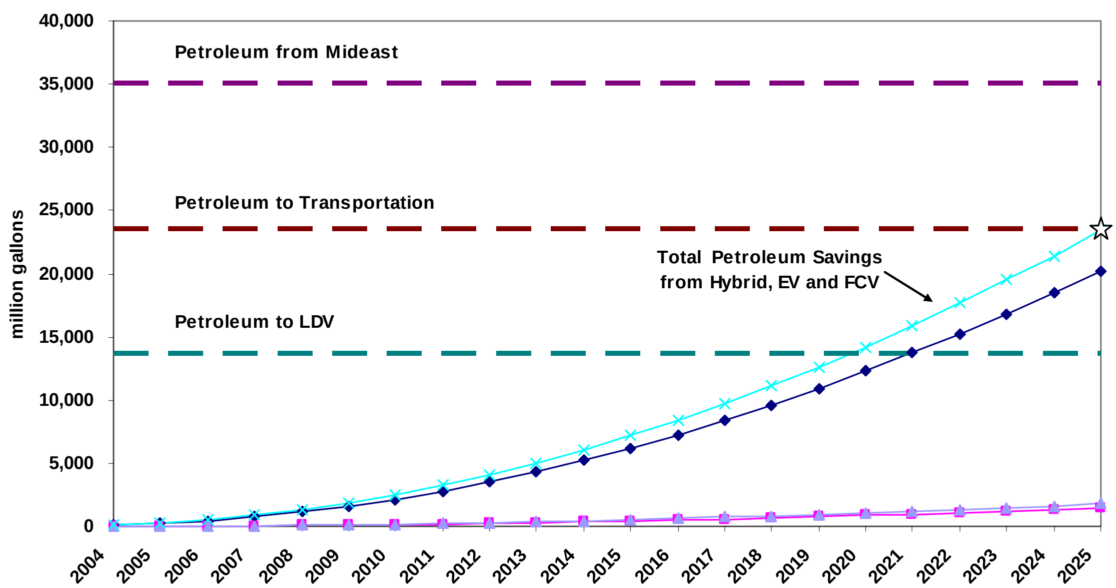

Figure 4-66: Petroleum Savings from New Vehicle Technologies (Scenario 2)

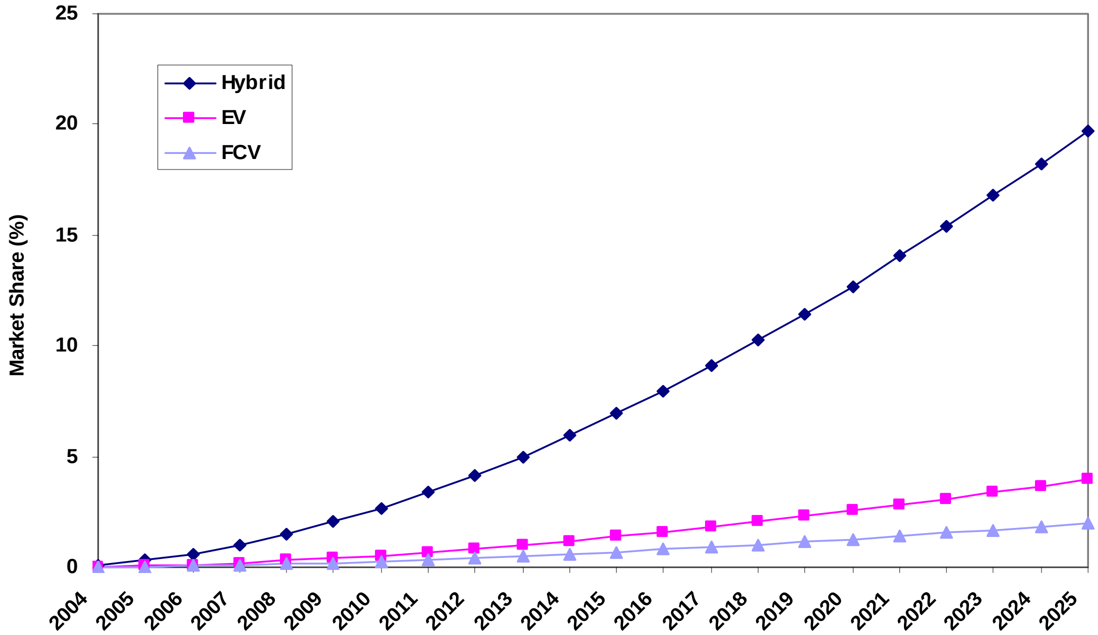

Figure 4-67: Market Penetration of New Vehicle Technologies (Scenario 3)

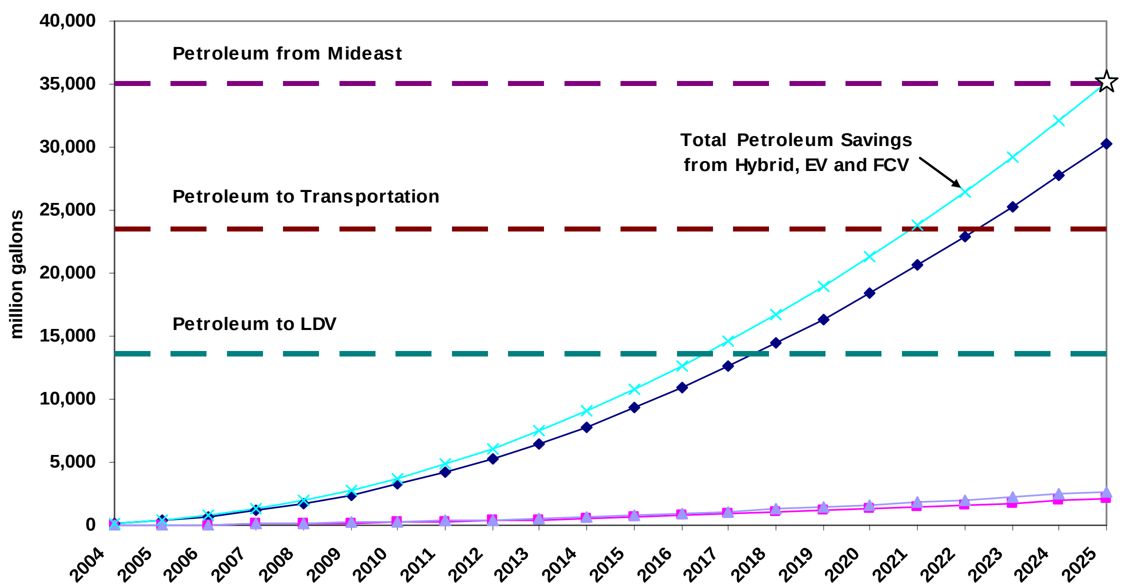

Figure 4-68: Petroleum Savings from New Vehicle Technologies (Scenario 3)

4.6 Summary

This Chapter calculates the total fuel consumption and emissions of the U.S. light-duty vehicle fleet from 2004-2030 with four models for fleet population, vehicle technology, driving behavior and traffic congestion. Based on that, this Chapter identifies the impacts of worsening traffic on the fleet fuel consumption and emissions and then investigates how to offset these impacts through methods beyond the transportation systems, such as altering vehicle choice (and then vehicle population), developing vehicle technology, as well as changing driving behavior.

The following major conclusions are made in this Chapter:

- If trends from the 1970s and early 2000 continue, SUV will be the largest source for fuel consumption and emissions of the U.S. light-duty vehicle fleet. On the contrary, Hybrid can considerably reduce the fleet fuel consumption and emissions.
- Compared to vehicle technology improvement and driving behavior change, the fleet population growth and worsening traffic congestion have greater impacts on the fuel consumption and emissions of the U.S. light-duty vehicle fleet.
- Promoting the market share of new vehicle technology (Hybrid mainly) is the most feasible and most effective method to offset the impacts of worsening traffic from 2004 to 2030, and more options become feasible with less strict assumptions for worsening traffic. Specifically, when the worsening traffic keeps the same trend as that in the past 20 years, its energy and environmental impacts on the U.S. light-duty vehicle fleet can be offset if the market share for Hybrid arrives at 29% by the end of 2030.
- For the above offset method (more Hybrids), the total economic benefits in 2030

from gasoline and carbon savings range 73-148 billion U.S. dollars (2004 value). And the total benefits are more sensitive to the change of gasoline price than that of carbon price.

- In the newly launched Advanced Energy Initiative, President Bush states the objective to reduce the U.S. petroleum imports, especially from the Middle East. This objective is feasible with the successful penetration of new vehicle technologies powered by alternative fuels.

CHAPTER 5: CONCLUSIONS

5.1 Thesis Summary

For sustainable mobility research, it is a very necessary and important task to quantitatively evaluate the increase of vehicle fuel consumption and emissions when traffic congestion becomes worse. On one hand, quantifying the energy and environmental impacts of worsening traffic can help us design feasible measures beyond transportation systems to “offset” these impacts. On the other hand, quantifying the energy and environmental impacts of worsening traffic can help us calculate the “on-road” fuel economy to compare the real performance of different vehicle technologies for both today’s and tomorrow’s traffic situations.

The vehicle performance under different driving situations provides the basis for analyzing the energy and environmental impacts of worsening traffic. However, the amount of the real-world driving situations is too huge to handle. Additionally, it is also unrealistic to identify the vehicle fuel consumption and emissions in each specific driving situation.

Under such a background, this thesis creatively defines the concept of “driving segments” to characterize all the driving situations as the combination of vehicle speed, operation patterns (Free Flow, Speed Up/Slow Down, Stop-and-Go) and road types (Highway, Suburban, Urban). The definition of “driving segments” describes the real-world driving situations in a simplified and systematic way by linking vehicle performance with traffic congestion. Further, using the ADVISOR 2004 software tool, the fuel consumption and emissions of 13 light-duty vehicle types under each “driving segment” are simulated and then developed into the “Driving Segments” vehicle performance matrices.

Combining the “Driving Segments” vehicle performance matrices with specific traffic congestion model, this thesis has examined the energy and environmental impacts of worsening traffic on individual light-duty vehicles. Meanwhile, combining the “Driving Segments” vehicle performance matrices with a set of models for fleet population, vehicle technology, driving behavior and traffic congestion, the energy and environmental impacts of worsening traffic on the U.S. light-duty vehicle fleet have also been examined in this thesis.

All the major conclusions from the above application of “Driving Segments” vehicle performance matrices are summarized as below.

5.2 Major Conclusions

About the impacts of worsening traffic on individual light-duty vehicles:

- The amount of fuel consumption and emissions from light-duty vehicles are underestimated because of the characteristics of the existing driving cycles.
- The “On-road” fuel economy for light-duty vehicles are normally 5 ~ 10 MPG lower and only equivalent to 60% ~ 70% of the “FEG” fuel economy developed by the U.S. EPA.
- In terms of the change of fuel consumption and CO_2 emissions, worsening traffic has the largest impacts on SUV while has the smallest impacts on Hybrid and EV.
- In terms of the change of fuel economy, worsening traffic has the largest impacts on FCV while has the smallest impacts on Small and Large Vans (but Vans have

very low MPG to begin with).

About the impacts of worsening traffic on the U.S. light-duty vehicle fleet:

- If trends from the 1970s and early 2000 continue, SUV will be the largest source for fuel consumption and emissions of the U.S. light-duty vehicle fleet. On the contrary, Hybrid can considerably reduce the fleet fuel consumption and emissions.
- Compared to vehicle technology improvement and driving behavior change, the fleet population growth and worsening traffic congestion have greater impacts on the fuel consumption and emissions of the U.S. light-duty vehicle fleet.
- Promoting the market share of new vehicle technology (Hybrid mainly) is the most feasible and most effective method to offset the impacts of worsening traffic from 2004 to 2030, and more options become feasible with less strict assumptions for worsening traffic. Specifically, when the worsening traffic keeps the same trend as that in the past 20 years, its energy and environmental impacts on the U.S. light-duty vehicle fleet can be offset if the market share for Hybrid arrives at 29% by the end of 2030.
- For the above offset method (more Hybrids), the total economic benefits in 2030 from gasoline and carbon savings range 73-148 billion U.S. dollars (2004 value). And the total benefits are more sensitive to the change of gasoline price than that of carbon price.
- In the newly launched Advanced Energy Initiative, President Bush states the objective to reduce the U.S. petroleum imports, especially from the Middle East. This objective is feasible with the successful penetration of new vehicle technologies powered by alternative fuels.

5.3 Future Work

In light of the experience and lessons learned from this thesis, the future work on "driving segments" analysis mainly includes the following two aspects:

First, improve the accuracy of "Driving Segments" vehicle performance matrices by using better simulation tools for vehicle performance or verifying the simulation results with credible experimental data.

Second, develop more detailed models to describe the changes of traffic congestion. Actually the traffic congestion model is even more crucial than the accuracy of "Driving Segments" vehicle performance matrices. In this thesis, the available model for traffic congestion is so rough that there is no need to differentiate vehicle speed when calculating the vehicle performance under different traffic situations. And therefore "Driving Segments" matrices have to be simplified as "Driving Segments" inventories. This case exactly explains the importance of traffic congestion model itself, although the definition of "driving segments" provides a lot of flexibility with different traffic models.

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APPENDIX

Program A-2-1: Data Analysis for Driving Situations

```
// transform.cpp : Defines the entry point for the console application.
//

#include "stdio.h"
#define N 6 //number of variables to average
#define IMAX 16 //number of blocks for velocity, 5 mph for each block
#define JMAX 14    //number of bolock for accerleration, 0.5 m/s^2 for each block

void main()
{
        char file_name_in[81];//raw data file name
        char file_name_out[81];//output file name
        char title[N+2][81];//titles of each variable
        FILE *fp_in,*fp_out;

        float sum[N][IMAX][JMAX];//sum of values in each block
        float num[IMAX][JMAX];//number of vaules in each block
        float V,A,value;//velocity, accerleration, and dumy variable
        int ii,jj;//velocity index, accerleration index

        printf("Please input the file name of raw data:\n");
       scanf("%s",file_name_in);
        fp_in=fopen(file_name_in,"r");

        while(fp_in==NULL){
                printf("A wrong file name! No such file!\n");
              printf("Please input the file name of raw data:\n");
              scanf("%s",file_name_in);
               fp_in=fopen(file_name_in,"r");
        }

        fseek( fp_in, 0L, SEEK_SET );//locate the pointer at start of file

        printf("Please input the file name of output:\n");
```

```
 scanf("%s",file_name_out);

 fp_out=fopen(file_name_out,"w");

for(int i=0;i<N+2;i++)fscanf(fp_in,"%s",title[i]);

 for(ii=0;ii<IMAX;ii++) //initialization
      for(jj=0;jj<JMAX;jj++)
        {
                for(i=0;i<N;i++)sum[i][ii][jj]=0.0;
                num[ii][jj]=0.0;
        }

 while (!feof(fp_in))
 {
      fscanf(fp_in,"%f",&V);
      fscanf(fp_in,"%f",&A);

        ii=(int)(V/5.0);
        jj=(int)((A+3.5)/0.5);

        if(ii>=0&&ii<IMAX&&jj>=0&&jj<JMAX&&!feof(fp_in))
        {
            for (i=0;i<N;i++)
                {
                   fscanf(fp_in,"%f",&value);
                       sum[i][ii][jj]+=value;
                }
                num[ii][jj]=num[ii][jj]+1;
        }
        else
                for(i=0;i<N;i++) fscanf(fp_in,"%f",&value);
}

 //output
 for(i=0;i<N+1;i++)fprintf(fp_out,"%s\t",title[i]);
fprintf(fp_out,"%s\n",title[N+1]);

 for(ii=0;ii<IMAX;ii++)
        for(jj=0;jj<JMAX;jj++)
        {
```

```
            fprintf(fp_out,"%d\t%d\t",ii+1,jj+1);
              for(i=0;i<N-1;i++)
              {
                  if(num[ii][jj]==0.0) fprintf(fp_out,"\t");
                  else
                    fprintf(fp_out,"%f\t",sum[i][ii][jj]/num[ii][jj]);
              }

            if(num[ii][jj]==0.0) fprintf(fp_out,"\n");
              else
                  fprintf(fp_out,"%f\n",sum[N-1][ii][jj]/num[ii][jj]);
        }

    fclose(fp_in);
    fclose(fp_out);
}
```

Table A-2-1: "Driving Segments" Vehicle Performance Matrices for Two-seater Car (Automatic Transmission)

Based on Time

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	1.213	1.100	1.066	1.113										
Suburban						1.368	1.129	0.909						
Urban Street								0.825	0.652	0.571				
Emissions-HC (g/s)														
Highway	0.002	0.002	0.002	0.006										
Suburban						0.002	0.002	0.002						
Urban								0.002	0.002	0.003				
Emissions-CO (g/s)														
Highway	0.038	0.033	0.031	0.127										
Suburban						0.044	0.035	0.030						
Urban								0.026	0.021	0.023				
Emissions-NO_x (g/s)														
Highway	0.003	0.003	0.002	0.004										
Suburban						0.003	0.002	0.002						
Urban								0.002	0.003	0.003				
Emissions-CO_2 (g/s)														
Highway	3.679	3.337	3.236	3.222										
Suburban						4.146	3.423	2.753						
Urban								2.499	1.974	1.720				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					0.994	1.056								
Suburban									0.745	0.640	0.593			
Urban											0.502	0.412		
Emissions-HC (g/s)														
Highway					0.002	0.002								
Suburban									0.002	0.002	0.003			
Urban											0.004	0.004		
Emissions-CO (g/s)														
Highway					0.035	0.031								
Suburban									0.037	0.027	0.035			
Urban											0.026	0.025		
Emissions-NOX (g/s)														
Highway					0.002	0.002								
Suburban									0.003	0.003	0.003			
Urban											0.003	0.003		
Emissions-CO2 (g/s)														
Highway					3.006	3.205								
Suburban									2.235	1.926	1.766			
Urban											1.498	1.221		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							1.159	0.934	0.756	0.642	0.601	0.527	0.363	0.225
Suburban												0.502	0.337	0.222
Urban													0.303	0.209
Emissions-HC (g/s)														
Highway							0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.002
Suburban												0.003	0.003	0.002
Urban													0.003	0.002
Emissions-CO (g/s)														
Highway							0.036	0.028	0.041	0.026	0.035	0.028	0.022	0.007
Suburban												0.028	0.019	0.008
Urban													0.015	0.007
Emissions-NOX (g/s)														
Highway							0.002	0.002	0.003	0.002	0.002	0.002	0.002	0.001
Suburban												0.002	0.002	0.001
Urban													0.002	0.001
Emissions-CO2 (g/s)														
Highway							3.516	2.836	2.262	1.934	1.792	1.574	1.078	0.679
Suburban												1.496	1.003	0.666
Urban													0.901	0.627

Based on Mileage

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	64.707	63.346	66.725	76.337										
Suburban						115.866	108.348	100.675						
Urban								91.329	85.309	91.360				
Emissions-HC (g/mile)														
Highway	0.120	0.130	0.125	0.377										
Suburban						0.194	0.192	0.208						
Urban								0.203	0.262	0.400				
Emissions-CO (g/mile)														
Highway	2.027	1.901	1.941	8.674										
Suburban						3.751	3.372	3.365						
Urban								2.862	2.705	3.627				
Emissions-NO_x (g/mile)														
Highway	0.147	0.158	0.141	0.274										
Suburban						0.230	0.228	0.222						
Urban								0.222	0.349	0.427				
Emissions-CO_2 (g/mile)														
Highway	196.227	192.226	202.586	220.920										
Suburban						351.215	328.632	304.892						
Urban								276.831	258.371	275.120				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					75.335	89.407								
Suburban									97.488	102.400	121.927			
Urban											103.200	118.656		
Emissions-HC (g/mile)														
Highway					0.164	0.155								
Suburban									0.314	0.384	0.679			
Urban											0.720	1.248		
Emissions-CO (g/mile)														
Highway					2.640	2.584								
Suburban									4.817	4.336	7.138			
Urban											5.417	7.296		
Emissions-NOX (g/mile)														
Highway					0.164	0.198								
Suburban									0.367	0.416	0.535			
Urban											0.583	0.864		
Emissions-CO2 (g/mile)														
Highway					227.836	271.482								
Suburban									292.516	308.160	363.230			
Urban											308.057	351.504		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							111.280	103.505	98.935	102.707	123.669	151.680	174.360	323.880
Suburban												144.547	161.952	319.104
Urban													145.280	300.960
Emissions-HC (g/mile)														
Highway							0.192	0.194	0.316	0.347	0.634	0.864	1.480	3.000
Suburban												0.950	1.344	3.456
Urban													1.520	3.360
Emissions-CO (g/mile)														
Highway							3.480	3.102	5.302	4.173	7.149	7.944	10.600	9.480
Suburban												8.122	9.216	11.088
Urban													7.120	10.560
Emissions-NOX (g/mile)														
Highway							0.200	0.203	0.360	0.373	0.480	0.600	1.000	1.800
Suburban												0.662	0.960	2.016
Urban													1.040	1.680
Emissions-CO2 (g/mile)														
Highway							337.496	314.105	296.171	309.467	368.726	453.408	517.200	977.280
Suburban												430.877	481.488	958.320
Urban													432.640	903.120

Table A-2-2: "Driving Segments" Vehicle Performance Matrices for Two-seater Car (Manual Transmission)

Based on Time

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	1.508	1.276	1.088	1.034										
Suburban						1.324	1.040	0.893						
Urban								0.737	0.587	0.513				
Emissions-HC (g/s)														
Highway	0.003	0.003	0.002	0.003										
Suburban						0.002	0.002	0.002						
Urban								0.002	0.002	0.003				
Emissions-CO (g/s)														
Highway	0.040	0.029	0.022	0.028										
Suburban						0.039	0.030	0.026						
Urban								0.019	0.010	0.019				
Emissions-NO_x (g/s)														
Highway	0.004	0.004	0.003	0.005										
Suburban						0.003	0.003	0.003						
Urban								0.003	0.003	0.003				
Emissions-CO_2 (g/s)														
Highway	4.583	3.889	3.318	3.140										
Suburban						4.019	3.158	2.710						
Urban								2.239	1.790	1.545				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					1.096	0.965								
Suburban									1.014	0.828	0.622			
Urban											0.417	0.347		
Emissions-HC (g/s)														
Highway					0.004	0.002								
Suburban									0.003	0.003	0.003			
Urban											0.003	0.004		
Emissions-CO (g/s)														
Highway					0.077	0.023								
Suburban									0.050	0.042	0.036			
Urban											0.014	0.013		
Emissions-NOX (g/s)														
Highway					0.003	0.003								
Suburban									0.005	0.003	0.003			
Urban											0.003	0.003		
Emissions-CO2 (g/s)														
Highway					3.250	2.937								
Suburban									3.041	2.482	1.854			
Urban											1.256	1.038		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							1.571	1.324	1.197	0.937	0.698	0.493	0.330	0.255
Suburban												0.427	0.307	0.249
Urban													0.279	0.228
Emissions-HC (g/s)														
Highway							0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.002
Suburban												0.003	0.002	0.003
Urban													0.003	0.003
Emissions-CO (g/s)														
Highway							0.052	0.041	0.065	0.044	0.043	0.019	0.010	0.007
Suburban												0.016	0.009	0.009
Urban													0.010	0.009
Emissions-NOX (g/s)														
Highway							0.003	0.003	0.006	0.003	0.003	0.002	0.002	0.001
Suburban												0.003	0.002	0.001
Urban													0.002	0.001
Emissions-CO2 (g/s)														
Highway							4.761	4.018	3.583	2.815	2.077	1.482	0.994	0.770
Suburban												1.283	0.927	0.748
Urban													0.838	0.683

Based on Mileage

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	80.400	73.498	68.103	70.903										
Suburban						112.163	99.852	98.945						
Urban								81.637	76.822	82.080				
Emissions-HC (g/mile)														
Highway	0.147	0.144	0.125	0.223										
Suburban						0.182	0.180	0.235						
Urban								0.222	0.262	0.453				
Emissions-CO (g/mile)														
Highway	2.147	1.642	1.393	1.920										
Suburban						3.340	2.916	2.880						
Urban								2.123	1.331	3.040				
Emissions-NO_x (g/mile)														
Highway	0.187	0.202	0.188	0.326										
Suburban						0.266	0.240	0.318						
Urban								0.314	0.371	0.453				
Emissions-CO_2 (g/mile)														
Highway	244.427	223.992	207.720	215.297										
Suburban						340.397	303.132	300.157						
Urban								247.957	234.284	247.227				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					83.027	81.741								
Suburban									132.689	132.496	127.975			
Urban											85.783	99.888		
Emissions-HC (g/mile)														
Highway					0.291	0.141								
Suburban									0.406	0.480	0.699			
Urban											0.686	1.104		
Emissions-CO (g/mile)														
Highway					5.861	1.920								
Suburban									6.572	6.688	7.447			
Urban											2.914	3.792		
Emissions-NO_x (g/mile)														
Highway					0.253	0.240								
Suburban									0.641	0.464	0.597			
Urban											0.549	0.768		
Emissions-CO_2 (g/mile)														
Highway					246.278	248.809								
Suburban									398.068	397.120	381.374			
Urban											258.377	298.992		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							150.800	146.695	156.687	149.947	143.503	141.912	158.280	367.080
Suburban												122.947	147.408	358.128
Urban													133.920	328.800
Emissions-HC (g/mile)														
Highway							0.216	0.249	0.447	0.467	0.703	0.864	1.240	3.120
Suburban												0.950	1.152	3.600
Urban													1.360	3.600
Emissions-CO (g/mile)														
Highway							4.984	4.505	8.520	7.107	8.777	5.544	4.960	10.560
Suburban												4.608	4.320	12.384
Urban													4.720	13.200
Emissions-NO_x (g/mile)														
Highway							0.248	0.305	0.742	0.453	0.566	0.696	0.800	1.800
Suburban												0.749	0.720	2.016
Urban													0.720	1.680
Emissions-CO_2 (g/mile)														
Highway							457.032	445.015	468.982	450.373	427.217	426.864	477.200	1108.200
Suburban												369.619	445.008	1076.400
Urban													402.400	984.000

Table A-2-3: “Driving Segments” Vehicle Performance Matrices for Subcompact Sedan (Automatic Transmission)

Based on Time

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	1.485	1.364	1.202	1.232										
Suburban						1.649	1.416	1.120						
Urban								0.975	0.794	0.718				
Emissions-HC (g/s)														
Highway	0.002	0.002	0.001	0.004										
Suburban						0.007	0.008	0.002						
Urban								0.002	0.002	0.002				
Emissions-CO (g/s)														
Highway	0.006	0.005	0.005	0.013										
Suburban						0.028	0.031	0.008						
Urban								0.009	0.008	0.011				
Emissions-NO_x (g/s)														
Highway	0.004	0.003	0.003	0.005										
Suburban						0.007	0.007	0.003						
Urban								0.003	0.002	0.002				
Emissions-CO_2 (g/s)														
Highway	4.571	4.198	3.699	3.769										
Suburban						5.025	4.302	3.438						
Urban								2.989	2.433	2.192				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					1.366	1.300								
Suburban									1.227	1.068	0.840			
Urban											0.600	0.501		
Emissions-HC (g/s)														
Highway					0.010	0.008								
Suburban									0.010	0.003	0.003			
Urban											0.003	0.003		
Emissions-CO (g/s)														
Highway					0.042	0.030								
Suburban									0.040	0.012	0.016			
Urban											0.013	0.015		
Emissions-NO_x (g/s)														
Highway					0.009	0.007								
Suburban									0.008	0.003	0.004			
Urban											0.002	0.002		
Emissions-CO_2 (g/s)														
Highway					4.120	3.943								
Suburban									3.694	3.271	2.557			
Urban											1.824	1.514		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							2.024	1.675	1.435	1.191	0.932	0.714	0.483	0.302
Suburban												0.650	0.432	0.299
Urban													0.385	0.285
Emissions-HC (g/s)														
Highway							0.051	0.040	0.031	0.018	0.003	0.003	0.002	0.001
Suburban												0.003	0.002	0.002
Urban													0.002	0.002
Emissions-CO (g/s)														
Highway							0.187	0.146	0.113	0.067	0.015	0.014	0.009	0.007
Suburban												0.014	0.009	0.008
Urban													0.010	0.008
Emissions-NO_x (g/s)														
Highway							0.032	0.026	0.020	0.012	0.004	0.003	0.001	0.000
Suburban												0.003	0.001	0.000
Urban													0.001	0.000
Emissions-CO_2 (g/s)														
Highway							5.804	4.823	4.161	3.518	2.845	2.172	1.470	0.918
Suburban												1.974	1.312	0.906
Urban													1.166	0.861

Based on Mileage

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	79.200	78.552	75.240	84.446										
Suburban						139.668	135.972	124.006						
Urban								107.945	103.964	114.880				
Emissions-HC (g/mile)														
Highway	0.093	0.086	0.078	0.274										
Suburban						0.617	0.744	0.194						
Urban								0.203	0.240	0.347				
Emissions-CO (g/mile)														
Highway	0.307	0.302	0.329	0.891										
Suburban						2.348	2.928	0.900						
Urban								0.942	1.091	1.760				
Emissions-NO_x (g/mile)														
Highway	0.187	0.144	0.157	0.309										
Suburban						0.581	0.648	0.305						
Urban								0.277	0.305	0.373				
Emissions-CO_2 (g/mile)														
Highway	243.800	241.776	231.574	258.463										
Suburban						425.611	412.968	380.769						
Urban								331.052	318.458	350.747				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					103.541	110.132								
Suburban									160.625	170.928	172.738			
Urban											123.463	144.384		
Emissions-HC (g/mile)														
Highway					0.783	0.664								
Suburban									1.348	0.416	0.699			
Urban											0.617	0.960		
Emissions-CO (g/mile)														
Highway					3.171	2.555								
Suburban									5.197	1.904	3.230			
Urban											2.640	4.320		
Emissions-NO_x (g/mile)														
Highway					0.657	0.565								
Suburban									1.073	0.544	0.741			
Urban											0.446	0.624		
Emissions-CO_2 (g/mile)														
Highway					312.227	333.981								
Suburban									483.631	523.392	526.094			
Urban											375.223	436.080		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							194.312	185.575	187.844	190.547	191.743	205.512	231.800	434.760
Suburban												187.085	207.216	430.560
Urban													184.960	409.680
Emissions-HC (g/mile)														
Highway							4.856	4.394	3.993	2.840	0.651	0.840	0.920	2.040
Suburban												0.864	0.912	2.304
Urban													1.040	2.160
Emissions-CO (g/mile)														
Highway							17.944	16.218	14.749	10.667	3.051	3.960	4.400	9.600
Suburban												4.118	4.464	11.232
Urban													4.880	11.520
Emissions-NO_x (g/mile)														
Highway							3.112	2.825	2.585	1.933	0.720	0.792	0.640	0.480
Suburban												0.778	0.576	0.576
Urban													0.480	0.240
Emissions-CO_2 (g/mile)														
Highway							557.152	534.231	544.756	562.947	585.154	625.608	705.640	1321.560
Suburban												568.368	629.616	1305.072
Urban													559.840	1239.360

Table A-2-4: “Driving Segments” Vehicle Performance Matrices for Subcompact Sedan (Manual Transmission)

Based on Time

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	1.741	1.512	1.219	1.237										
Suburban						1.592	1.270	1.042						
Urban								0.876	0.725	0.640				
Emissions-HC (g/s)														
Highway	0.002	0.002	0.002	0.004										
Suburban						0.006	0.007	0.002						
Urban								0.002	0.002	0.002				
Emissions-CO (g/s)														
Highway	0.007	0.006	0.005	0.015										
Suburban						0.025	0.028	0.009						
Urban								0.009	0.009	0.011				
Emissions-NO_x (g/s)														
Highway	0.004	0.003	0.003	0.004										
Suburban						0.006	0.006	0.003						
Urban								0.003	0.002	0.002				
Emissions-CO_2 (g/s)														
Highway	5.357	4.652	3.752	3.785										
Suburban						4.854	3.856	3.196						
Urban								2.683	2.218	1.953				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					1.271	1.237								
Suburban									1.071	0.891	0.713			
Urban											0.526	0.435		
Emissions-HC (g/s)														
Highway					0.009	0.007								
Suburban									0.009	0.002	0.003			
Urban											0.003	0.003		
Emissions-CO (g/s)														
Highway					0.038	0.027								
Suburban									0.035	0.012	0.016			
Urban											0.012	0.013		
Emissions-NO_x (g/s)														
Highway					0.008	0.006								
Suburban									0.007	0.003	0.003			
Urban											0.002	0.001		
Emissions-CO_2 (g/s)														
Highway					3.837	3.753								
Suburban									3.225	2.725	2.166			
Urban											1.597	1.311		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							1.978	1.622	1.330	1.102	0.814	0.609	0.423	0.353
Suburban												0.559	0.394	0.342
Urban													0.361	0.314
Emissions-HC (g/s)														
Highway							0.055	0.042	0.031	0.021	0.003	0.003	0.002	0.002
Suburban												0.003	0.002	0.002
Urban													0.002	0.002
Emissions-CO (g/s)														
Highway							0.202	0.157	0.115	0.078	0.015	0.014	0.009	0.008
Suburban												0.014	0.009	0.009
Urban													0.010	0.009
Emissions-NO_x (g/s)														
Highway							0.035	0.027	0.020	0.014	0.003	0.002	0.001	0.001
Suburban												0.002	0.001	0.001
Urban													0.001	0.000
Emissions-CO_2 (g/s)														
Highway							5.625	4.634	3.834	3.218	2.481	1.850	1.284	1.072
Suburban												1.694	1.195	1.036
Urban													1.091	0.949

Based on Mileage

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	92.840	87.062	76.336	84.840										
Suburban						134.828	121.944	115.394						
Urban								97.015	94.844	102.427				
Emissions-HC (g/mile)														
Highway	0.120	0.086	0.094	0.257										
Suburban						0.545	0.672	0.194						
Urban								0.203	0.240	0.320				
Emissions-CO (g/mile)														
Highway	0.347	0.346	0.329	1.029										
Suburban						2.142	2.664	0.969						
Urban								1.015	1.156	1.707				
Emissions-NO_x (g/mile)														
Highway	0.213	0.187	0.157	0.291										
Suburban						0.520	0.588	0.291						
Urban								0.277	0.284	0.320				
Emissions-CO_2 (g/mile)														
Highway	285.693	267.926	234.923	259.509										
Suburban						411.150	370.188	354.032						
Urban								297.157	290.291	312.400				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					96.316	104.739								
Suburban									140.138	142.592	146.613			
Urban											108.171	125.136		
Emissions-HC (g/mile)														
Highway					0.707	0.579								
Suburban									1.139	0.384	0.658			
Urban											0.514	0.816		
Emissions-CO (g/mile)														
Highway					2.855	2.315								
Suburban									4.529	1.920	3.189			
Urban											2.400	3.840		
Emissions-NO_x (g/mile)														
Highway					0.568	0.494								
Suburban									0.916	0.464	0.638			
Urban											0.343	0.384		
Emissions-CO_2 (g/mile)														
Highway					290.779	317.915								
Suburban									422.129	435.984	445.577			
Urban											328.491	377.568		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							189.928	179.695	174.153	176.373	167.537	175.488	202.800	507.600
Suburban												160.877	188.928	491.904
Urban													173.040	451.680
Emissions-HC (g/mile)														
Highway							5.256	4.689	4.047	3.320	0.651	0.792	0.880	2.520
Suburban												0.778	0.864	2.880
Urban													0.960	2.880
Emissions-CO (g/mile)														
Highway							19.424	17.391	15.055	12.547	3.051	4.008	4.360	11.280
Suburban												4.032	4.320	13.104
Urban													4.800	13.200
Emissions-NO_x (g/mile)														
Highway							3.376	3.018	2.618	2.213	0.634	0.696	0.600	0.840
Suburban												0.605	0.528	0.864
Urban													0.480	0.480
Emissions-CO_2 (g/mile)														
Highway							540.016	513.332	501.873	514.800	510.463	532.920	616.520	1542.960
Suburban												487.728	573.792	1491.120
Urban													523.680	1366.080

Table A-2-5: "Driving Segments" Vehicle Performance Matrices for Compact Sedan (Automatic Transmission)

Based on Time

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	1.489	1.355	1.182	1.260										
Suburban						1.628	1.444	1.284						
Urban								1.046	0.848	0.774				
Emissions-HC (g/s)														
Highway	0.002	0.002	0.001	0.004										
Suburban						0.011	0.007	0.006						
Urban								0.002	0.002	0.002				
Emissions-CO (g/s)														
Highway	0.006	0.006	0.005	0.011										
Suburban						0.045	0.027	0.022						
Urban								0.008	0.010	0.012				
Emissions-NO_x (g/s)														
Highway	0.003	0.003	0.002	0.004										
Suburban						0.009	0.006	0.005						
Urban								0.003	0.003	0.003				
Emissions-CO_2 (g/s)														
Highway	4.583	4.171	3.638	3.860										
Suburban						4.920	4.396	3.912						
Urban								3.211	2.597	2.365				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					1.506	1.312								
Suburban									1.387	1.165	0.905			
Urban											0.645	0.528		
Emissions-HC (g/s)														
Highway					0.012	0.004								
Suburban									0.009	0.003	0.003			
Urban											0.003	0.004		
Emissions-CO (g/s)														
Highway					0.050	0.016								
Suburban									0.036	0.013	0.015			
Urban											0.013	0.016		
Emissions-NO_x (g/s)														
Highway					0.010	0.004								
Suburban									0.008	0.004	0.004			
Urban											0.002	0.002		
Emissions-CO_2 (g/s)														
Highway					4.536	4.014								
Suburban									4.198	3.570	2.761			
Urban											1.962	1.593		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							1.961	1.741	1.591	1.259	1.021	0.752	0.513	0.309
Suburban												0.650	0.460	0.305
Urban													0.401	0.291
Emissions-HC (g/s)														
Highway							0.013	0.010	0.012	0.002	0.004	0.004	0.002	0.001
Suburban												0.003	0.002	0.002
Urban													0.002	0.002
Emissions-CO (g/s)														
Highway							0.051	0.038	0.046	0.012	0.016	0.016	0.010	0.007
Suburban												0.014	0.010	0.008
Urban													0.011	0.008
Emissions-NO_x (g/s)														
Highway							0.011	0.009	0.010	0.004	0.004	0.003	0.002	0.000
Suburban												0.003	0.002	0.001
Urban													0.001	0.000
Emissions-CO_2 (g/s)														
Highway							5.933	5.285	4.803	3.860	3.117	2.285	1.562	0.941
Suburban												1.975	1.398	0.925
Urban													1.214	0.879

Based on Mileage

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	79.413	78.048	73.988	86.366										
Suburban						137.901	138.648	142.214						
Urban								115.883	110.989	123.893				
Emissions-HC (g/mile)														
Highway	0.080	0.086	0.078	0.257										
Suburban						0.968	0.660	0.609						
Urban								0.203	0.284	0.347				
Emissions-CO (g/mile)														
Highway	0.320	0.317	0.297	0.771										
Suburban						3.812	2.580	2.409						
Urban								0.905	1.244	1.867				
Emissions-NO_x (g/mile)														
Highway	0.173	0.158	0.141	0.291										
Suburban						0.787	0.612	0.582						
Urban								0.295	0.327	0.427				
Emissions-CO_2 (g/mile)														
Highway	244.400	240.221	227.770	264.703										
Suburban						416.789	421.992	433.343						
Urban								355.643	339.927	378.373				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					114.164	111.162								
Suburban									181.545	186.432	186.213			
Urban											132.651	151.920		
Emissions-HC (g/mile)														
Highway					0.935	0.339								
Suburban									1.204	0.416	0.699			
Urban											0.617	1.008		
Emissions-CO (g/mile)														
Highway					3.802	1.355								
Suburban									4.726	2.000	3.147			
Urban											2.743	4.608		
Emissions-NO_x (g/mile)														
Highway					0.783	0.367								
Suburban									1.034	0.576	0.720			
Urban											0.480	0.672		
Emissions-CO_2 (g/mile)														
Highway					343.743	339.995								
Suburban									549.556	571.136	567.977			
Urban											403.577	458.736		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							188.208	192.877	208.211	201.373	210.120	216.480	246.440	445.560
Suburban												187.142	220.608	439.632
Urban													192.400	418.320
Emissions-HC (g/mile)														
Highway							1.272	1.108	1.560	0.387	0.737	1.056	1.160	2.040
Suburban												0.864	1.008	2.304
Urban													1.120	2.160
Emissions-CO (g/mile)														
Highway							4.864	4.228	6.022	1.840	3.377	4.584	5.000	9.720
Suburban												4.032	4.656	11.376
Urban													5.120	11.760
Emissions-NO_x (g/mile)														
Highway							1.064	0.969	1.298	0.573	0.789	0.864	0.800	0.600
Suburban												0.720	0.720	0.720
Urban													0.640	0.480
Emissions-CO_2 (g/mile)														
Highway							569.568	585.388	628.713	617.573	641.280	657.960	749.560	1354.440
Suburban												568.829	670.800	1332.432
Urban													582.720	1265.040

Table A-2-6: "Driving Segments" Vehicle Performance Matrices for Compact Sedan (Manual Transmission)

Based on Time

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	1.903	1.558	1.215	1.289										
Suburban						1.833	1.328	1.221						
Urban								0.966	0.767	0.690				
Emissions-HC (g/s)														
Highway	0.002	0.002	0.002	0.004										
Suburban						0.017	0.006	0.005						
Urban								0.002	0.002	0.002				
Emissions-CO (g/s)														
Highway	0.007	0.006	0.005	0.011										
Suburban						0.065	0.026	0.022						
Urban								0.009	0.009	0.011				
Emissions-NO_x (g/s)														
Highway	0.004	0.003	0.003	0.004										
Suburban						0.013	0.006	0.005						
Urban								0.003	0.002	0.002				
Emissions-CO_2 (g/s)														
Highway	5.858	4.796	3.740	3.952										
Suburban						5.506	4.039	3.717						
Urban								2.961	2.346	2.106				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					1.436	1.206								
Suburban									1.191	0.970	0.790			
Urban											0.565	0.455		
Emissions-HC (g/s)														
Highway					0.012	0.004								
Suburban									0.009	0.002	0.003			
Urban											0.003	0.003		
Emissions-CO (g/s)														
Highway					0.047	0.015								
Suburban									0.034	0.012	0.015			
Urban											0.012	0.014		
Emissions-NO_x (g/s)														
Highway					0.010	0.004								
Suburban									0.007	0.003	0.003			
Urban											0.002	0.002		
Emissions-CO_2 (g/s)														
Highway					4.325	3.689								
Suburban									3.598	2.968	2.405			
Urban											1.717	1.375		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							1.841	1.685	1.399	1.033	0.948	0.657	0.441	0.361
Suburban												0.564	0.412	0.349
Urban													0.372	0.321
Emissions-HC (g/s)														
Highway							0.012	0.009	0.010	0.002	0.003	0.003	0.002	0.002
Suburban												0.003	0.002	0.002
Urban													0.002	0.002
Emissions-CO (g/s)														
Highway							0.047	0.037	0.040	0.011	0.017	0.015	0.010	0.008
Suburban												0.013	0.009	0.009
Urban													0.010	0.009
Emissions-NO_x (g/s)														
Highway							0.010	0.008	0.008	0.003	0.004	0.003	0.001	0.001
Suburban												0.002	0.001	0.001
Urban													0.001	0.001
Emissions-CO_2 (g/s)														
Highway							5.576	5.116	4.224	3.163	2.890	1.996	1.340	1.096
Suburban												1.713	1.252	1.058
Urban													1.126	0.969

Based on Mileage

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	101.493	89.741	76.085	88.354										
Suburban						155.254	127.452	135.194						
Urban								106.985	100.364	110.427				
Emissions-HC (g/mile)														
Highway	0.093	0.101	0.094	0.240										
Suburban						1.404	0.612	0.582						
Urban								0.185	0.262	0.347				
Emissions-CO (g/mile)														
Highway	0.387	0.346	0.313	0.720										
Suburban						5.530	2.484	2.465						
Urban								1.015	1.200	1.813				
Emissions-NO_x (g/mile)														
Highway	0.227	0.187	0.172	0.257										
Suburban						1.113	0.564	0.582						
Urban								0.295	0.305	0.373				
Emissions-CO_2 (g/mile)														
Highway	312.400	276.250	234.141	270.994										
Suburban						466.403	387.744	411.674						
Urban								328.006	307.091	336.933				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					108.859	102.155								
Suburban									155.952	155.200	162.411			
Urban											116.194	131.088		
Emissions-HC (g/mile)														
Highway					0.872	0.311								
Suburban									1.126	0.384	0.617			
Urban											0.514	0.864		
Emissions-CO (g/mile)														
Highway					3.587	1.242								
Suburban									4.451	1.904	3.003			
Urban											2.503	4.080		
Emissions-NO_x (g/mile)														
Highway					0.745	0.325								
Suburban									0.943	0.480	0.617			
Urban											0.377	0.480		
Emissions-CO_2 (g/mile)														
Highway					327.815	312.494								
Suburban									470.998	474.912	494.743			
Urban											353.109	395.856		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							176.728	186.618	183.076	165.200	195.000	189.312	211.760	519.360
Suburban												162.374	197.760	502.848
Urban													178.560	461.520
Emissions-HC (g/mile)														
Highway							1.104	0.997	1.331	0.360	0.703	0.960	1.000	2.520
Suburban												0.778	0.864	2.880
Urban													0.960	2.880
Emissions-CO (g/mile)														
Highway							4.480	4.062	5.247	1.720	3.429	4.272	4.600	11.400
Suburban												3.686	4.272	13.104
Urban													4.720	12.960
Emissions-NO_x (g/mile)														
Highway							0.944	0.905	1.091	0.467	0.737	0.768	0.600	1.080
Suburban												0.605	0.528	1.152
Urban													0.480	0.720
Emissions-CO_2 (g/mile)														
Highway							535.256	566.686	552.905	506.147	594.463	574.920	643.120	1578.480
Suburban												493.258	600.816	1523.664
Urban													540.240	1395.360

Table A-2-7: “Driving Segments” Vehicle Performance Matrices for Midsize Sedan (Automatic Transmission)

Based on Time

Velocity Pattern: Free Flow / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	1.513	1.387	1.234	1.314										
Suburban						1.860	1.423	1.361						
Urban								1.073	0.884	0.804				
Emissions-HC (g/s)														
Highway	0.002	0.002	0.002	0.003										
Suburban						0.017	0.007	0.005						
Urban								0.002	0.002	0.002				
Emissions-CO (g/s)														
Highway	0.006	0.006	0.005	0.011										
Suburban						0.066	0.026	0.022						
Urban								0.008	0.009	0.012				
Emissions-NO_x (g/s)														
Highway	0.003	0.003	0.002	0.004										
Suburban						0.013	0.006	0.005						
Urban								0.003	0.003	0.003				
Emissions-CO_2 (g/s)														
Highway	4.656	4.269	3.799	4.028										
Suburban						5.589	4.332	4.150						
Urban								3.294	2.709	2.455				

Velocity Pattern: Speed Up/Slow Down / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					1.544	1.352								
Suburban									1.434	1.190	0.930			
Urban											0.666	0.542		
Emissions-HC (g/s)														
Highway					0.012	0.004								
Suburban									0.009	0.003	0.003			
Urban											0.003	0.004		
Emissions-CO (g/s)														
Highway					0.047	0.016								
Suburban									0.035	0.012	0.015			
Urban											0.014	0.016		
Emissions-NO_x (g/s)														
Highway					0.010	0.005								
Suburban									0.008	0.004	0.004			
Urban											0.003	0.003		
Emissions-CO_2 (g/s)														
Highway					4.656	4.137								
Suburban									4.345	3.646	2.836			
Urban											2.026	1.637		

Velocity Pattern: Stop and Go / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							1.846	1.882	1.641	1.280	1.043	0.776	0.531	0.300
Suburban												0.673	0.474	0.292
Urban													0.410	0.294
Emissions-HC (g/s)														
Highway							0.013	0.010	0.012	0.003	0.003	0.004	0.002	0.001
Suburban												0.003	0.002	0.002
Urban													0.002	0.002
Emissions-CO (g/s)														
Highway							0.049	0.038	0.045	0.011	0.016	0.016	0.010	0.007
Suburban												0.014	0.010	0.008
Urban													0.011	0.008
Emissions-NO_x (g/s)														
Highway							0.011	0.009	0.010	0.004	0.004	0.003	0.002	0.000
Suburban												0.003	0.002	0.001
Urban													0.001	0.000
Emissions-CO_2 (g/s)														
Highway							5.584	5.721	4.958	3.925	3.185	2.359	1.615	0.910
Suburban												2.047	1.440	0.885
Urban													1.241	0.888

Based on Mileage

Velocity Pattern: Free Flow / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	80.693	79.891	77.275	90.069										
Suburban						157.589	136.608	150.702						
Urban								118.874	115.767	128.640				
Emissions-HC (g/mile)														
Highway	0.080	0.086	0.094	0.223										
Suburban						1.428	0.636	0.595						
Urban								0.203	0.262	0.373				
Emissions-CO (g/mile)														
Highway	0.320	0.317	0.297	0.720										
Suburban						5.578	2.508	2.382						
Urban								0.905	1.178	1.893				
Emissions-NO_x (g/mile)														
Highway	0.173	0.158	0.141	0.274										
Suburban						1.137	0.588	0.595						
Urban								0.295	0.349	0.427				
Emissions-CO_2 (g/mile)														
Highway	248.333	245.894	237.819	276.206										
Suburban						473.445	415.884	459.678						
Urban								364.911	354.611	392.827				

Velocity Pattern: Speed Up/Slow Down / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					116.994	114.508								
Suburban									187.750	190.384	191.232			
Urban											137.006	156.144		
Emissions-HC (g/mile)														
Highway					0.897	0.339								
Suburban									1.165	0.432	0.638			
Urban											0.583	1.008		
Emissions-CO (g/mile)														
Highway					3.587	1.327								
Suburban									4.608	1.952	3.127			
Urban											2.846	4.704		
Emissions-NO_x (g/mile)														
Highway					0.758	0.381								
Suburban									1.034	0.576	0.761			
Urban											0.549	0.720		
Emissions-CO_2 (g/mile)														
Highway					352.876	350.386								
Suburban									568.826	583.312	583.467			
Urban											416.674	471.504		

Velocity Pattern: Stop and Go / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							177.240	208.495	214.756	204.733	214.594	223.392	254.920	431.520
Suburban												193.824	227.328	421.056
Urban													196.800	422.640
Emissions-HC (g/mile)														
Highway							1.240	1.098	1.527	0.400	0.669	1.056	1.120	2.040
Suburban												0.864	1.008	2.304
Urban													1.120	2.160
Emissions-CO (g/mile)														
Highway							4.736	4.191	5.913	1.800	3.291	4.560	5.000	9.840
Suburban												3.974	4.608	11.520
Urban													5.200	11.520
Emissions-NO_x (g/mile)														
Highway							1.032	0.988	1.287	0.573	0.806	0.888	0.800	0.600
Suburban												0.749	0.720	0.720
Urban													0.640	0.480
Emissions-CO_2 (g/mile)														
Highway							536.032	633.748	649.069	627.933	655.183	679.248	775.360	1310.520
Suburban												589.450	691.152	1274.544
Urban													595.760	1278.480

Table A-2-8: “Driving Segments” Vehicle Performance Matrices for Midsize Sedan (Manual Transmission)

Based on Time

Velocity Pattern: Free Flow / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	1.940	1.610	1.277	1.337										
Suburban						1.879	1.376	1.258						
Urban								1.009	0.799	0.716				
Emissions-HC (g/s)														
Highway	0.002	0.002	0.002	0.004										
Suburban						0.017	0.006	0.005						
Urban								0.002	0.002	0.002				
Emissions-CO (g/s)														
Highway	0.008	0.006	0.005	0.011										
Suburban						0.068	0.026	0.021						
Urban								0.009	0.009	0.011				
Emissions-NO_x (g/s)														
Highway	0.005	0.003	0.003	0.004										
Suburban						0.014	0.006	0.005						
Urban								0.003	0.002	0.002				
Emissions-CO_2 (g/s)														
Highway	5.973	4.955	3.929	4.101										
Suburban						5.642	4.189	3.834						
Urban								3.095	2.444	2.184				

Velocity Pattern: Speed Up/Slow Down / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					1.486	1.253								
Suburban									1.229	0.991	0.813			
Urban											0.581	0.468		
Emissions-HC (g/s)														
Highway					0.012	0.004								
Suburban									0.009	0.002	0.003			
Urban											0.003	0.003		
Emissions-CO (g/s)														
Highway					0.048	0.017								
Suburban									0.034	0.012	0.015			
Urban											0.013	0.014		
Emissions-NO_x (g/s)														
Highway					0.010	0.004								
Suburban									0.007	0.003	0.003			
Urban											0.002	0.002		
Emissions-CO_2 (g/s)														
Highway					4.479	3.828								
Suburban									3.714	3.034	2.478			
Urban											1.765	1.412		

Velocity Pattern: Stop and Go / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							1.869	1.692	1.429	1.050	0.979	0.683	0.451	0.366
Suburban												0.583	0.421	0.354
Urban													0.378	0.324
Emissions-HC (g/s)														
Highway							0.012	0.008	0.010	0.002	0.004	0.003	0.002	0.002
Suburban												0.003	0.002	0.002
Urban													0.002	0.002
Emissions-CO (g/s)														
Highway							0.046	0.033	0.040	0.011	0.016	0.015	0.010	0.008
Suburban												0.013	0.009	0.009
Urban													0.010	0.009
Emissions-NO_x (g/s)														
Highway							0.010	0.008	0.008	0.003	0.004	0.003	0.001	0.001
Suburban												0.002	0.001	0.001
Urban													0.001	0.001
Emissions-CO_2 (g/s)														
Highway							5.663	5.146	4.317	3.218	2.985	2.076	1.371	1.111
Suburban												1.772	1.278	1.072
Urban													1.144	0.978

Based on Mileage

Velocity Pattern: Free Flow / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	103.480	92.722	79.951	91.663										
Suburban						159.150	132.120	139.306						
Urban								111.766	104.531	114.480				
Emissions-HC (g/mile)														
Highway	0.093	0.101	0.094	0.240										
Suburban						1.452	0.612	0.540						
Urban								0.185	0.284	0.347				
Emissions-CO (g/mile)														
Highway	0.400	0.360	0.329	0.720										
Suburban						5.760	2.472	2.285						
Urban								0.997	1.200	1.813				
Emissions-NO_x (g/mile)														
Highway	0.240	0.187	0.172	0.291										
Suburban						1.162	0.564	0.554						
Urban								0.295	0.305	0.373				
Emissions-CO_2 (g/mile)														
Highway	318.560	285.394	246.005	281.177										
Suburban						477.886	402.108	424.717						
Urban								342.812	319.942	349.387				

Velocity Pattern: Speed Up/Slow Down / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					112.648	106.108								
Suburban									160.861	158.592	167.287			
Urban											119.451	134.640		
Emissions-HC (g/mile)														
Highway					0.909	0.353								
Suburban									1.126	0.384	0.658			
Urban											0.583	0.864		
Emissions-CO (g/mile)														
Highway					3.600	1.426								
Suburban									4.425	1.856	2.983			
Urban											2.571	4.128		
Emissions-NO_x (g/mile)														
Highway					0.758	0.367								
Suburban									0.943	0.480	0.679			
Urban											0.446	0.480		
Emissions-CO_2 (g/mile)														
Highway					339.423	324.254								
Suburban									486.236	485.392	509.842			
Urban											363.086	406.560		

Velocity Pattern: Stop and Go / Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							179.416	187.431	187.004	168.013	201.326	196.800	216.560	526.440
Suburban												167.990	201.888	509.184
Urban													181.440	465.840
Emissions-HC (g/mile)														
Highway							1.104	0.914	1.320	0.360	0.720	0.984	1.040	2.640
Suburban												0.778	0.912	3.024
Urban													1.040	2.880
Emissions-CO (g/mile)														
Highway							4.408	3.692	5.193	1.680	3.377	4.296	4.640	11.280
Suburban												3.715	4.320	13.104
Urban													4.800	12.960
Emissions-NO_x (g/mile)														
Highway							0.960	0.849	1.102	0.467	0.789	0.768	0.600	1.200
Suburban												0.605	0.528	1.296
Urban													0.480	0.960
Emissions-CO_2 (g/mile)														
Highway							543.600	569.991	565.145	514.867	614.091	597.816	658.000	1600.200
Suburban												510.394	613.488	1543.104
Urban													549.280	1407.840

Table A-2-9: “Driving Segments” Vehicle Performance Matrices for Large Sedan (Automatic Transmission)

Based on Time

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway	1.491	1.360	1.195	1.270										
Suburban						1.750	1.450	1.287						
Urban								1.060	0.856	0.783				
	Emissions-HC (g/s)													
Highway	0.002	0.002	0.001	0.004										
Suburban						0.017	0.007	0.005						
Urban								0.002	0.002	0.002				
	Emissions-CO (g/s)													
Highway	0.006	0.006	0.005	0.011										
Suburban						0.066	0.027	0.022						
Urban								0.008	0.009	0.012				
	Emissions-NO_x (g/s)													
Highway	0.003	0.003	0.002	0.004										
Suburban						0.013	0.006	0.005						
Urban								0.003	0.003	0.003				
	Emissions-CO_2 (g/s)													
Highway	4.589	4.186	3.676	3.894										
Suburban						5.248	4.415	3.924						
Urban								3.254	2.623	2.391				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway					1.519	1.323								
Suburban									1.403	1.171	0.912			
Urban											0.651	0.532		
	Emissions-HC (g/s)													
Highway					0.012	0.004								
Suburban									0.009	0.003	0.003			
Urban											0.003	0.004		
	Emissions-CO (g/s)													
Highway					0.048	0.016								
Suburban									0.036	0.013	0.015			
Urban											0.013	0.016		
	Emissions-NO_x (g/s)													
Highway					0.010	0.004								
Suburban									0.008	0.004	0.004			
Urban											0.003	0.002		
	Emissions-CO_2 (g/s)													
Highway					4.577	4.047								
Suburban									4.249	3.588	2.782			
Urban											1.980	1.606		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway							1.954	1.726	1.610	1.263	1.027	0.759	0.519	0.311
Suburban												0.657	0.464	0.307
Urban													0.404	0.291
	Emissions-HC (g/s)													
Highway							0.013	0.010	0.012	0.002	0.003	0.004	0.002	0.001
Suburban												0.003	0.002	0.002
Urban													0.002	0.002
	Emissions-CO (g/s)													
Highway							0.050	0.038	0.046	0.012	0.016	0.016	0.010	0.007
Suburban												0.014	0.010	0.008
Urban													0.011	0.008
	Emissions-NO_x (g/s)													
Highway							0.011	0.009	0.010	0.004	0.004	0.003	0.002	0.000
Suburban												0.003	0.002	0.001
Urban													0.001	0.000
	Emissions-CO_2 (g/s)													
Highway							5.915	5.241	4.864	3.873	3.134	2.306	1.578	0.945
Suburban												1.996	1.411	0.929
Urban													1.223	0.882

Based on Mileage

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway	79.507	78.336	74.802	87.069										
Suburban						148.211	139.212	142.588						
Urban								117.415	112.080	125.280				
	Emissions-HC (g/mile)													
Highway	0.080	0.086	0.078	0.240										
Suburban						1.416	0.648	0.595						
Urban								0.203	0.284	0.347				
	Emissions-CO (g/mile)													
Highway	0.320	0.317	0.297	0.737										
Suburban						5.591	2.556	2.382						
Urban								0.905	1.222	1.893				
	Emissions-NO_x (g/mile)													
Highway	0.173	0.158	0.141	0.291										
Suburban						1.113	0.600	0.582						
Urban								0.295	0.327	0.427				
	Emissions-CO_2 (g/mile)													
Highway	244.720	241.114	230.150	266.983										
Suburban						444.500	423.792	434.617						
Urban								360.406	343.353	382.613				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway					115.137	112.066								
Suburban									183.692	187.360	187.570			
Urban											133.886	153.120		
	Emissions-HC (g/mile)													
Highway					0.922	0.339								
Suburban									1.204	0.416	0.658			
Urban											0.583	1.008		
	Emissions-CO (g/mile)													
Highway					3.651	1.355								
Suburban									4.713	2.000	3.106			
Urban											2.743	4.608		
	Emissions-NO_x (g/mile)													
Highway					0.771	0.367								
Suburban									1.034	0.576	0.741			
Urban											0.514	0.672		
	Emissions-CO_2 (g/mile)													
Highway					346.914	342.791								
Suburban									556.233	574.000	572.194			
Urban											407.314	462.432		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway							187.608	191.234	210.818	202.040	211.200	218.472	249.120	447.480
Suburban												189.101	222.768	441.360
Urban													193.840	419.520
	Emissions-HC (g/mile)													
Highway							1.264	1.098	1.571	0.387	0.686	1.056	1.120	2.040
Suburban												0.864	1.008	2.304
Urban													1.120	2.160
	Emissions-CO (g/mile)													
Highway							4.832	4.191	6.022	1.840	3.309	4.536	4.960	9.480
Suburban												3.974	4.608	11.088
Urban													5.120	11.520
	Emissions-NO_x (g/mile)													
Highway							1.056	0.960	1.298	0.573	0.789	0.864	0.800	0.600
Suburban												0.720	0.720	0.720
Urban													0.640	0.480
	Emissions-CO_2 (g/mile)													
Highway							567.808	580.486	636.796	619.667	644.726	664.104	757.640	1360.680
Suburban												574.934	677.184	1338.192
Urban													586.800	1269.360

Table A-2-10: “Driving Segments” Vehicle Performance Matrices for Large Sedan (Manual Transmission)

Based on Time

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway	1.907	1.567	1.229	1.301										
Suburban						1.849	1.344	1.235						
Urban								0.979	0.778	0.697				
	Emissions-HC (g/s)													
Highway	0.002	0.002	0.002	0.003										
Suburban						0.017	0.006	0.005						
Urban								0.002	0.002	0.002				
	Emissions-CO (g/s)													
Highway	0.007	0.006	0.005	0.010										
Suburban						0.067	0.026	0.022						
Urban								0.009	0.009	0.011				
	Emissions-NO_x (g/s)													
Highway	0.004	0.003	0.003	0.004										
Suburban						0.014	0.006	0.005						
Urban								0.003	0.002	0.002				
	Emissions-CO_2 (g/s)													
Highway	5.871	4.823	3.781	3.989										
Suburban						5.551	4.089	3.761						
Urban								3.001	2.380	2.126				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway					1.450	1.219								
Suburban									1.208	0.975	0.802			
Urban											0.570	0.459		
	Emissions-HC (g/s)													
Highway					0.012	0.004								
Suburban									0.009	0.002	0.003			
Urban											0.003	0.003		
	Emissions-CO (g/s)													
Highway					0.047	0.016								
Suburban									0.034	0.012	0.015			
Urban											0.012	0.014		
	Emissions-NO_x (g/s)													
Highway					0.010	0.004								
Suburban									0.007	0.003	0.003			
Urban											0.002	0.002		
	Emissions-CO_2 (g/s)													
Highway					4.367	3.725								
Suburban									3.651	2.983	2.443			
Urban											1.732	1.387		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway							1.849	1.692	1.413	1.036	0.961	0.664	0.444	0.363
Suburban												0.569	0.415	0.351
Urban													0.374	0.322
	Emissions-HC (g/s)													
Highway							0.012	0.009	0.010	0.002	0.003	0.003	0.002	0.002
Suburban												0.003	0.002	0.002
Urban													0.002	0.002
	Emissions-CO (g/s)													
Highway							0.046	0.036	0.040	0.011	0.017	0.015	0.010	0.008
Suburban												0.013	0.009	0.009
Urban													0.010	0.009
	Emissions-NO_x (g/s)													
Highway							0.010	0.008	0.008	0.003	0.004	0.003	0.001	0.001
Suburban												0.002	0.001	0.001
Urban													0.001	0.001
	Emissions-CO_2 (g/s)													
Highway							5.601	5.139	4.268	3.174	2.930	2.017	1.349	1.102
Suburban												1.728	1.260	1.063
Urban													1.131	0.973

Based on Mileage

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway	101.720	90.259	76.915	89.177										
Suburban						156.609	129.012	136.786						
Urban								108.388	101.804	111.440				
	Emissions-HC (g/mile)													
Highway	0.093	0.101	0.094	0.223										
Suburban						1.428	0.612	0.582						
Urban								0.185	0.262	0.347				
	Emissions-CO (g/mile)													
Highway	0.387	0.346	0.313	0.703										
Suburban						5.699	2.460	2.437						
Urban								0.978	1.200	1.813				
	Emissions-NO_x (g/mile)													
Highway	0.227	0.187	0.172	0.257										
Suburban						1.150	0.564	0.568						
Urban								0.295	0.305	0.373				
	Emissions-CO_2 (g/mile)													
Highway	313.093	277.776	236.692	273.514										
Suburban						470.227	392.532	416.631						
Urban								332.363	311.520	340.133				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway					109.869	103.214								
Suburban									158.177	155.936	164.880			
Urban											117.223	132.288		
	Emissions-HC (g/mile)													
Highway					0.884	0.325								
Suburban									1.126	0.384	0.617			
Urban											0.514	0.864		
	Emissions-CO (g/mile)													
Highway					3.575	1.341								
Suburban									4.438	1.888	2.983			
Urban											2.537	4.128		
	Emissions-NO_x (g/mile)													
Highway					0.745	0.353								
Suburban									0.943	0.480	0.617			
Urban											0.411	0.480		
	Emissions-CO_2 (g/mile)													
Highway					330.973	315.544								
Suburban									477.936	477.232	502.457			
Urban											356.331	399.360		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway							177.536	187.449	184.953	165.693	197.606	191.304	213.200	522.120
Suburban												163.843	199.056	505.296
Urban													179.440	463.440
	Emissions-HC (g/mile)													
Highway							1.104	0.988	1.320	0.360	0.686	0.960	1.040	2.640
Suburban												0.778	0.912	3.024
Urban													1.040	2.880
	Emissions-CO (g/mile)													
Highway							4.424	4.025	5.215	1.707	3.394	4.296	4.560	11.400
Suburban												3.715	4.272	13.104
Urban													4.800	12.960
	Emissions-NO_x (g/mile)													
Highway							0.944	0.886	1.102	0.467	0.737	0.768	0.600	1.200
Suburban												0.605	0.528	1.296
Urban													0.480	0.960
	Emissions-CO_2 (g/mile)													
Highway							537.728	569.271	558.753	507.760	602.657	581.016	647.680	1586.760
Suburban												497.750	604.800	1531.152
Urban													542.960	1401.120

Table A-2-11: “Driving Segments” Vehicle Performance Matrices for Small Pickup (Automatic Transmission)

Based on Time

Velocity Pattern: Free Flow														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	2.122	1.767	1.664	1.901										
Suburban						2.556	1.919	1.794						
Urban								1.404	1.210	1.073				
Emissions-HC (g/s)														
Highway	0.004	0.003	0.003	0.008										
Suburban						0.034	0.005	0.014						
Urban								0.006	0.006	0.007				
Emissions-CO (g/s)														
Highway	0.013	0.010	0.012	0.043										
Suburban						0.421	0.032	0.215						
Urban								0.030	0.028	0.025				
Emissions-NO_x (g/s)														
Highway	0.012	0.010	0.010	0.014										
Suburban						0.034	0.015	0.019						
Urban								0.018	0.016	0.014				
Emissions-CO_2 (g/s)														
Highway	6.521	5.430	5.109	5.779										
Suburban						7.127	5.856	5.159						
Urban								4.272	3.677	3.254				

Velocity Pattern: Speed Up/Slow Down														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					1.879	1.633								
Suburban									1.908	1.338	1.151			
Urban											0.923	0.821		
Emissions-HC (g/s)														
Highway					0.024	0.008								
Suburban									0.015	0.007	0.009			
Urban											0.007	0.009		
Emissions-CO (g/s)														
Highway					0.142	0.027								
Suburban									0.116	0.028	0.040			
Urban											0.030	0.028		
Emissions-NO_x (g/s)														
Highway					0.035	0.018								
Suburban									0.030	0.017	0.020			
Urban											0.012	0.011		
Emissions-CO_2 (g/s)														
Highway					5.508	4.976								
Suburban									5.663	4.067	3.466			
Urban											2.782	2.466		

Velocity Pattern: Stop and Go														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							2.483	2.369	2.202	1.395	1.173	0.992	0.731	0.535
Suburban												0.967	0.696	0.523
Urban													0.630	0.490
Emissions-HC (g/s)														
Highway							0.005	0.023	0.018	0.007	0.009	0.009	0.007	0.004
Suburban												0.009	0.006	0.005
Urban													0.007	0.005
Emissions-CO (g/s)														
Highway							0.040	0.452	0.148	0.024	0.044	0.032	0.020	0.012
Suburban												0.029	0.017	0.013
Urban													0.018	0.013
Emissions-NO_x (g/s)														
Highway							0.013	0.017	0.032	0.015	0.022	0.014	0.008	0.005
Suburban												0.013	0.007	0.005
Urban													0.007	0.005
Emissions-CO_2 (g/s)														
Highway							7.591	6.536	6.511	4.249	3.526	2.985	2.205	1.621
Suburban												2.913	2.103	1.580
Urban													1.895	1.478

Based on Mileage

Velocity Pattern: Free Flow														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	113.160	101.750	104.165	130.337										
Suburban						216.484	184.176	198.678						
Urban								155.557	158.444	171.600				
Emissions-HC (g/mile)														
Highway	0.187	0.173	0.203	0.549										
Suburban						2.880	0.504	1.523						
Urban								0.628	0.742	1.067				
Emissions-CO (g/mile)														
Highway	0.693	0.547	0.736	2.914										
Suburban						35.685	3.096	23.788						
Urban								3.342	3.644	3.920				
Emissions-NO_x (g/mile)														
Highway	0.613	0.562	0.595	0.960										
Suburban						2.856	1.440	2.105						
Urban								1.957	2.051	2.187				
Emissions-CO_2 (g/mile)														
Highway	347.760	312.754	319.868	396.257										
Suburban						603.687	562.212	571.486						
Urban								473.169	481.309	520.640				

Velocity Pattern: Speed Up/Slow Down														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					142.383	138.339								
Suburban									249.801	214.096	236.818			
Urban											189.806	236.544		
Emissions-HC (g/mile)														
Highway					1.781	0.706								
Suburban									2.003	1.152	1.769			
Urban											1.406	2.592		
Emissions-CO (g/mile)														
Highway					10.737	2.245								
Suburban									15.172	4.400	8.311			
Urban											6.171	7.920		
Emissions-NO_x (g/mile)														
Highway					2.615	1.496								
Suburban									3.940	2.640	4.053			
Urban											2.469	3.264		
Emissions-CO_2 (g/mile)														
Highway					417.423	421.496								
Suburban									741.377	650.720	712.985			
Urban											572.366	710.256		

Velocity Pattern: Stop and Go														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							238.336	262.431	288.240	223.147	241.286	285.720	350.680	770.160
Suburban												278.352	333.840	752.544
Urban													302.160	706.080
Emissions-HC (g/mile)														
Highway							0.488	2.566	2.389	1.053	1.903	2.688	3.200	6.000
Suburban												2.448	2.832	6.768
Urban													3.120	6.960
Emissions-CO (g/mile)														
Highway							3.832	50.012	19.331	3.880	8.949	9.096	9.400	16.800
Suburban												8.381	8.160	18.864
Urban													8.800	18.960
Emissions-NO_x (g/mile)														
Highway							1.208	1.855	4.211	2.467	4.577	4.104	4.000	6.840
Suburban												3.830	3.456	7.344
Urban													3.520	7.200
Emissions-CO_2 (g/mile)														
Highway							728.696	724.015	852.393	679.760	725.314	859.776	1058.520	2334.600
Suburban												838.944	1009.536	2275.056
Urban													909.760	2127.840

Table A-2-12: “Driving Segments” Vehicle Performance Matrices for Small Pickup (Manual Transmission)

Based on Time

Velocity Pattern: Free Flow														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	2.479	2.110	1.639	1.677										
Suburban						2.768	1.732	2.061						
Urban								1.558	1.219	0.981				
Emissions-HC (g/s)														
Highway	0.004	0.004	0.003	0.008										
Suburban						0.033	0.012	0.007						
Urban								0.007	0.006	0.007				
Emissions-CO (g/s)														
Highway	0.024	0.024	0.010	0.027										
Suburban						0.440	0.051	0.060						
Urban								0.048	0.029	0.028				
Emissions-NO_x (g/s)														
Highway	0.013	0.011	0.009	0.013										
Suburban						0.029	0.021	0.016						
Urban								0.017	0.015	0.012				
Emissions-CO_2 (g/s)														
Highway	7.602	6.465	5.033	5.112										
Suburban						7.758	5.230	6.250						
Urban								4.714	3.697	2.965				

Velocity Pattern: Speed Up/Slow Down														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					1.921	1.728								
Suburban									1.744	1.066	0.856			
Urban											0.799	0.715		
Emissions-HC (g/s)														
Highway					0.026	0.010								
Suburban									0.015	0.007	0.008			
Urban											0.007	0.008		
Emissions-CO (g/s)														
Highway					0.086	0.045								
Suburban									0.083	0.026	0.026			
Urban											0.021	0.023		
Emissions-NO_x (g/s)														
Highway					0.033	0.016								
Suburban									0.027	0.012	0.012			
Urban											0.009	0.009		
Emissions-CO_2 (g/s)														
Highway					5.719	5.235								
Suburban									5.209	3.231	2.580			
Urban											2.413	2.147		

Velocity Pattern: Stop and Go														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							1.937	2.410	1.903	1.022	0.859	0.785	0.633	0.580
Suburban												0.778	0.617	0.566
Urban													0.579	0.520
Emissions-HC (g/s)														
Highway							0.019	0.006	0.018	0.006	0.008	0.008	0.006	0.005
Suburban												0.007	0.005	0.006
Urban													0.006	0.006
Emissions-CO (g/s)														
Highway							0.080	0.052	0.100	0.022	0.029	0.025	0.017	0.014
Suburban												0.022	0.015	0.016
Urban													0.017	0.015
Emissions-NO_x (g/s)														
Highway							0.020	0.011	0.029	0.010	0.013	0.010	0.007	0.005
Suburban												0.009	0.006	0.006
Urban													0.007	0.005
Emissions-CO_2 (g/s)														
Highway							5.796	7.344	5.665	3.102	2.583	2.363	1.909	1.754
Suburban												2.347	1.866	1.708
Urban													1.743	1.565

Based on Mileage

Velocity Pattern: Free Flow														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	132.187	121.507	102.584	114.977										
Suburban						234.454	166.224	228.337						
Urban								172.523	159.513	156.933				
Emissions-HC (g/mile)														
Highway	0.200	0.202	0.203	0.566										
Suburban						2.771	1.188	0.748						
Urban								0.757	0.829	1.040				
Emissions-CO (g/mile)														
Highway	1.280	1.382	0.642	1.817										
Suburban						37.271	4.908	6.674						
Urban								5.298	3.818	4.480				
Emissions-NO_x (g/mile)														
Highway	0.680	0.619	0.579	0.909										
Suburban						2.420	1.968	1.731						
Urban								1.865	2.007	1.867				
Emissions-CO_2 (g/mile)														
Highway	405.440	372.370	315.125	350.503										
Suburban						657.136	502.032	692.322						
Urban								522.166	483.949	474.347				

Velocity Pattern: Speed Up/Slow Down														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					145.579	146.358								
Suburban									228.305	170.608	176.112			
Urban											164.331	205.872		
Emissions-HC (g/mile)														
Highway					1.945	0.861								
Suburban									1.964	1.040	1.543			
Urban											1.406	2.304		
Emissions-CO (g/mile)														
Highway					6.531	3.826								
Suburban									10.905	4.176	5.307			
Urban											4.286	6.720		
Emissions-NO_x (g/mile)														
Highway					2.501	1.384								
Suburban									3.535	1.888	2.366			
Urban											1.920	2.592		
Emissions-CO_2 (g/mile)														
Highway					433.402	443.393								
Suburban									681.840	516.992	530.702			
Urban											496.354	618.288		

Velocity Pattern: Stop and Go														
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							185.920	266.908	249.120	163.453	176.777	226.200	303.760	834.720
Suburban												224.122	296.160	814.896
Urban													277.920	749.040
Emissions-HC (g/mile)														
Highway							1.840	0.609	2.291	0.907	1.629	2.304	2.800	7.200
Suburban												2.074	2.496	8.064
Urban													2.800	8.400
Emissions-CO (g/mile)														
Highway							7.712	5.769	13.113	3.560	6.017	7.104	8.280	19.920
Suburban												6.394	7.152	22.320
Urban													7.920	21.360
Emissions-NO_x (g/mile)														
Highway							1.888	1.228	3.742	1.653	2.760	2.904	3.360	7.560
Suburban												2.650	2.928	8.064
Urban													3.120	7.680
Emissions-CO_2 (g/mile)														
Highway							556.432	813.489	741.644	496.240	531.360	680.400	916.360	2526.240
Suburban												675.821	895.584	2459.088
Urban													836.800	2254.080

Table A-2-13: “Driving Segments” Vehicle Performance Matrices for Large Pickup (Automatic Transmission)

Based on Time

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway	2.448	2.192	2.185	2.306										
Suburban						2.989	2.287	2.327						
Urban								1.868	1.428	1.165				
	Emissions-HC (g/s)													
Highway	0.005	0.004	0.004	0.009										
Suburban						0.006	0.005	0.006						
Urban								0.006	0.006	0.006				
	Emissions-CO (g/s)													
Highway	0.013	0.013	0.022	0.042										
Suburban						0.082	0.050	0.067						
Urban								0.046	0.029	0.023				
	Emissions-NO_x (g/s)													
Highway	0.015	0.012	0.012	0.015										
Suburban						0.011	0.011	0.013						
Urban								0.015	0.016	0.015				
	Emissions-CO_2 (g/s)													
Highway	7.527	6.736	6.699	7.029										
Suburban						9.083	6.969	7.062						
Urban								5.679	4.345	3.544				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway					2.299	2.211								
Suburban									1.978	1.296	1.184			
Urban											1.014	0.874		
	Emissions-HC (g/s)													
Highway					0.006	0.005								
Suburban									0.014	0.006	0.008			
Urban											0.007	0.009		
	Emissions-CO (g/s)													
Highway					0.048	0.044								
Suburban									0.099	0.023	0.032			
Urban											0.030	0.030		
	Emissions-NO_x (g/s)													
Highway					0.012	0.011								
Suburban									0.025	0.015	0.018			
Urban											0.013	0.013		
	Emissions-CO_2 (g/s)													
Highway					7.005	6.743								
Suburban									5.912	3.947	3.581			
Urban											3.063	2.625		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway							2.580	2.615	2.146	1.276	1.185	1.025	0.767	0.554
Suburban												1.014	0.733	0.540
Urban													0.671	0.501
	Emissions-HC (g/s)													
Highway							0.005	0.005	0.016	0.006	0.008	0.009	0.006	0.004
Suburban												0.008	0.006	0.005
Urban													0.007	0.005
	Emissions-CO (g/s)													
Highway							0.074	0.079	0.125	0.020	0.031	0.028	0.018	0.011
Suburban												0.026	0.017	0.013
Urban													0.019	0.013
	Emissions-NO_x (g/s)													
Highway							0.008	0.009	0.026	0.014	0.017	0.014	0.008	0.005
Suburban												0.013	0.007	0.005
Urban													0.008	0.005
	Emissions-CO_2 (g/s)													
Highway							7.837	7.934	6.380	3.893	3.587	3.093	2.320	1.681
Suburban												3.065	2.219	1.635
Urban													2.022	1.511

Based on Mileage

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway	130.573	126.274	136.784	158.143										
Suburban						253.210	219.588	257.732						
Urban								206.935	186.873	186.427				
	Emissions-HC (g/mile)													
Highway	0.240	0.216	0.235	0.583										
Suburban						0.520	0.516	0.665						
Urban								0.646	0.720	1.013				
	Emissions-CO (g/mile)													
Highway	0.667	0.749	1.393	2.897										
Suburban						6.946	4.800	7.422						
Urban								5.132	3.753	3.653				
	Emissions-NO_x (g/mile)													
Highway	0.787	0.706	0.736	1.029										
Suburban						0.956	1.068	1.412						
Urban								1.606	2.051	2.320				
	Emissions-CO_2 (g/mile)													
Highway	401.453	388.008	419.431	482.006										
Suburban						769.420	668.988	782.211						
Urban								629.040	568.844	566.960				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway					174.240	187.271								
Suburban									258.991	207.328	243.566			
Urban											208.594	251.808		
	Emissions-HC (g/mile)													
Highway					0.455	0.424								
Suburban									1.780	1.024	1.625			
Urban											1.440	2.688		
	Emissions-CO (g/mile)													
Highway					3.638	3.741								
Suburban									12.934	3.616	6.603			
Urban											6.103	8.496		
	Emissions-NO_x (g/mile)													
Highway					0.872	0.932								
Suburban									3.207	2.416	3.621			
Urban											2.709	3.600		
	Emissions-CO_2 (g/mile)													
Highway					530.905	571.144								
Suburban									773.987	631.504	736.745			
Urban											630.103	756.000		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway							247.712	289.634	280.909	204.213	243.789	295.152	368.080	797.640
Suburban												292.090	351.936	778.176
Urban													322.160	721.200
	Emissions-HC (g/mile)													
Highway							0.456	0.545	2.127	0.920	1.611	2.592	3.080	6.120
Suburban												2.390	2.784	7.056
Urban													3.200	7.200
	Emissions-CO (g/mile)													
Highway							7.144	8.769	16.353	3.160	6.343	8.016	8.640	15.960
Suburban												7.574	8.112	18.576
Urban													9.200	18.480
	Emissions-NO_x (g/mile)													
Highway							0.776	1.015	3.349	2.173	3.514	3.936	3.880	6.600
Suburban												3.859	3.552	7.344
Urban													3.760	7.200
	Emissions-CO_2 (g/mile)													
Highway							752.304	878.871	835.255	622.880	737.897	890.904	1113.400	2420.520
Suburban												882.806	1065.168	2353.824
Urban													970.400	2175.360

Table A-2-14: “Driving Segments” Vehicle Performance Matrices for Large Pickup (Manual Transmission)

Based on Time

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway	3.507	2.740	2.235	2.148										
Suburban						3.240	2.598	2.579						
Urban								1.805	1.401	1.084				
	Emissions-HC (g/s)													
Highway	0.006	0.005	0.004	0.009										
Suburban						0.006	0.006	0.007						
Urban								0.007	0.006	0.007				
	Emissions-CO (g/s)													
Highway	0.083	0.048	0.024	0.032										
Suburban						0.096	0.071	0.129						
Urban								0.109	0.045	0.023				
	Emissions-NO_x (g/s)													
Highway	0.013	0.012	0.012	0.016										
Suburban						0.010	0.010	0.012						
Urban								0.014	0.015	0.012				
	Emissions-CO_2 (g/s)													
Highway	10.682	8.371	6.853	6.557										
Suburban						9.835	7.893	7.738						
Urban								5.384	4.236	3.290				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway					2.462	2.362								
Suburban									1.578	1.054	0.923			
Urban											0.904	0.743		
	Emissions-HC (g/s)													
Highway					0.007	0.005								
Suburban									0.014	0.006	0.007			
Urban											0.007	0.008		
	Emissions-CO (g/s)													
Highway					0.057	0.053								
Suburban									0.097	0.019	0.020			
Urban											0.021	0.025		
	Emissions-NO_x (g/s)													
Highway					0.012	0.010								
Suburban									0.018	0.010	0.010			
Urban											0.010	0.010		
	Emissions-CO_2 (g/s)													
Highway					7.492	7.193								
Suburban									4.678	3.209	2.799			
Urban											2.736	2.231		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/s)													
Highway							3.625	3.571	1.600	0.993	0.890	0.786	0.646	0.599
Suburban												0.789	0.633	0.585
Urban													0.602	0.537
	Emissions-HC (g/s)													
Highway							0.022	0.017	0.018	0.005	0.006	0.007	0.005	0.005
Suburban												0.007	0.005	0.005
Urban													0.006	0.006
	Emissions-CO (g/s)													
Highway							0.227	0.214	0.121	0.016	0.019	0.020	0.014	0.013
Suburban												0.020	0.014	0.015
Urban													0.017	0.014
	Emissions-NO_x (g/s)													
Highway							0.016	0.013	0.019	0.009	0.010	0.008	0.006	0.005
Suburban												0.009	0.006	0.006
Urban													0.007	0.006
	Emissions-CO_2 (g/s)													
Highway							10.768	10.636	4.695	3.027	2.698	2.373	1.954	1.817
Suburban												2.383	1.916	1.767
Urban													1.814	1.618

Based on Mileage

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway	187.027	157.824	139.946	147.291										
Suburban						274.471	249.384	285.646						
Urban								199.975	183.404	173.360				
	Emissions-HC (g/mile)													
Highway	0.320	0.274	0.250	0.583										
Suburban						0.532	0.540	0.775						
Urban								0.738	0.829	1.067				
	Emissions-CO (g/mile)													
Highway	4.400	2.779	1.487	2.211										
Suburban						8.120	6.816	14.331						
Urban								12.037	5.891	3.653				
	Emissions-NO_x (g/mile)													
Highway	0.693	0.706	0.736	1.080										
Suburban						0.883	0.996	1.288						
Urban								1.495	1.942	1.973				
	Emissions-CO_2 (g/mile)													
Highway	569.693	482.141	429.026	449.640										
Suburban						833.107	757.728	857.132						
Urban								596.382	554.487	526.320				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway					186.606	200.047								
Suburban									206.575	168.640	189.957			
Urban											185.897	214.032		
	Emissions-HC (g/mile)													
Highway					0.518	0.424								
Suburban									1.833	0.912	1.399			
Urban											1.474	2.400		
	Emissions-CO (g/mile)													
Highway					4.333	4.504								
Suburban									12.633	2.976	4.135			
Urban											4.354	7.248		
	Emissions-NO_x (g/mile)													
Highway					0.884	0.861								
Suburban									2.409	1.664	2.098			
Urban											2.091	2.736		
	Emissions-CO_2 (g/mile)													
Highway					567.777	609.318								
Suburban									612.445	513.360	575.877			
Urban											562.869	642.384		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	Fuel Consumption (g/mile)													
Highway							347.960	395.520	209.476	158.933	182.983	226.416	309.840	862.800
Suburban												227.088	303.696	841.824
Urban													288.880	773.280
	Emissions-HC (g/mile)													
Highway							2.144	1.929	2.400	0.800	1.320	2.112	2.560	6.720
Suburban												1.958	2.400	7.776
Urban													2.880	7.920
	Emissions-CO (g/mile)													
Highway							21.792	23.742	15.895	2.547	3.909	5.808	6.920	18.000
Suburban												5.674	6.720	21.024
Urban													7.920	20.640
	Emissions-NO_x (g/mile)													
Highway							1.536	1.385	2.433	1.453	1.971	2.424	3.040	7.320
Suburban												2.448	2.928	8.208
Urban													3.280	8.160
	Emissions-CO_2 (g/mile)													
Highway							1033.680	1178.095	614.575	484.347	554.966	683.544	937.960	2616.720
Suburban												686.333	919.680	2544.192
Urban													870.640	2329.920

Table A-2-15: "Driving Segments" Vehicle Performance Matrices for Small Van (Automatic Transmission)

Based on Time

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	2.650	2.455	2.514	2.593										
Suburban						3.109	2.565	2.515						
Urban								2.012	1.466	1.213				
Emissions-HC (g/s)														
Highway	0.005	0.004	0.004	0.008										
Suburban						0.006	0.013	0.006						
Urban								0.006	0.006	0.007				
Emissions-CO (g/s)														
Highway	0.013	0.019	0.034	0.079										
Suburban						0.087	0.162	0.078						
Urban								0.054	0.028	0.023				
Emissions-NO_x (g/s)														
Highway	0.016	0.014	0.012	0.012										
Suburban						0.011	0.016	0.012						
Urban								0.014	0.016	0.014				
Emissions-CO_2 (g/s)														
Highway	8.147	7.536	7.695	7.860										
Suburban						9.445	7.628	7.625						
Urban								6.110	4.467	3.689				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					2.524	2.437								
Suburban									1.829	1.302	1.192			
Urban											1.042	0.892		
Emissions-HC (g/s)														
Highway					0.005	0.005								
Suburban									0.013	0.006	0.007			
Urban											0.007	0.009		
Emissions-CO (g/s)														
Highway					0.058	0.058								
Suburban									0.081	0.023	0.029			
Urban											0.030	0.030		
Emissions-NO_x (g/s)														
Highway					0.010	0.010								
Suburban									0.023	0.015	0.015			
Urban											0.013	0.013		
Emissions-CO_2 (g/s)														
Highway					7.687	7.419								
Suburban									5.481	3.965	3.612			
Urban											3.148	2.677		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							2.898	2.807	1.917	1.270	1.186	1.035	0.778	0.565
Suburban												1.030	0.746	0.551
Urban													0.688	0.507
Emissions-HC (g/s)														
Highway							0.024	0.005	0.015	0.005	0.007	0.009	0.006	0.004
Suburban												0.008	0.006	0.005
Urban													0.007	0.005
Emissions-CO (g/s)														
Highway							0.328	0.091	0.101	0.020	0.027	0.027	0.018	0.011
Suburban												0.025	0.017	0.013
Urban													0.019	0.013
Emissions-NO_x (g/s)														
Highway							0.019	0.008	0.025	0.013	0.014	0.013	0.008	0.005
Suburban												0.013	0.007	0.005
Urban													0.008	0.005
Emissions-CO_2 (g/s)														
Highway							8.362	8.508	5.716	3.872	3.597	3.127	2.358	1.716
Suburban												3.116	2.261	1.669
Urban													2.073	1.531

Based on Mileage

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	141.320	141.379	157.383	177.823										
Suburban						263.326	246.276	278.598						
Urban								222.905	191.935	194.053				
Emissions-HC (g/mile)														
Highway	0.240	0.245	0.266	0.549										
Suburban						0.484	1.272	0.651						
Urban								0.628	0.742	1.040				
Emissions-CO (g/mile)														
Highway	0.707	1.066	2.129	5.383										
Suburban						7.369	15.516	8.585						
Urban								5.982	3.622	3.707				
Emissions-NO_x (g/mile)														
Highway	0.840	0.792	0.751	0.840										
Suburban						0.920	1.512	1.302						
Urban								1.514	2.051	2.293				
Emissions-CO_2 (g/mile)														
Highway	434.480	434.088	481.743	538.971										
Suburban						800.023	732.252	844.657						
Urban								676.818	584.705	590.240				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					191.318	206.428								
Suburban									239.367	208.288	245.191			
Urban											214.251	256.848		
Emissions-HC (g/mile)														
Highway					0.404	0.395								
Suburban									1.636	0.960	1.461			
Urban											1.440	2.688		
Emissions-CO (g/mile)														
Highway					4.358	4.927								
Suburban									10.564	3.744	5.986			
Urban											6.103	8.688		
Emissions-NO_x (g/mile)														
Highway					0.720	0.847								
Suburban									3.063	2.320	3.127			
Urban											2.743	3.696		
Emissions-CO_2 (g/mile)														
Highway					582.619	628.447								
Suburban									717.565	634.320	743.122			
Urban											647.520	771.072		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							278.232	310.975	250.942	203.160	243.874	297.960	373.640	813.960
Suburban												296.582	358.224	794.016
Urban													330.080	730.320
Emissions-HC (g/mile)														
Highway							2.296	0.563	1.942	0.867	1.406	2.472	3.000	6.000
Suburban												2.275	2.736	6.912
Urban													3.200	6.960
Emissions-CO (g/mile)														
Highway							31.440	10.117	13.167	3.253	5.589	7.632	8.400	15.960
Suburban												7.258	8.016	18.576
Urban													9.280	18.480
Emissions-NO_x (g/mile)														
Highway							1.776	0.914	3.251	2.067	2.931	3.600	3.680	6.600
Suburban												3.600	3.504	7.344
Urban													3.920	7.200
Emissions-CO_2 (g/mile)														
Highway							802.776	942.471	748.265	619.533	739.903	900.576	1131.680	2471.640
Suburban												897.379	1085.424	2402.784
Urban													995.200	2204.400

Table A-2-16: "Driving Segments" Vehicle Performance Matrices for Small Van (Manual Transmission)

Based on Time

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	3.622	3.047	2.581	2.672										
Suburban						3.103	2.940	2.453						
Urban								1.956	1.437	1.203				
Emissions-HC (g/s)														
Highway	0.006	0.005	0.004	0.009										
Suburban						0.043	0.024	0.016						
Urban								0.006	0.007	0.007				
Emissions-CO (g/s)														
Highway	0.082	0.059	0.034	0.089										
Suburban						1.218	0.732	0.378						
Urban								0.058	0.079	0.040				
Emissions-NO_x (g/s)														
Highway	0.014	0.013	0.013	0.014										
Suburban						0.019	0.012	0.013						
Urban								0.013	0.013	0.012				
Emissions-CO_2 (g/s)														
Highway	11.037	9.298	7.902	8.082										
Suburban						7.537	7.853	6.933						
Urban								5.930	4.295	3.630				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					3.311	2.400								
Suburban									1.395	1.125	0.937			
Urban											0.918	0.749		
Emissions-HC (g/s)														
Highway					0.044	0.013								
Suburban									0.017	0.006	0.006			
Urban											0.007	0.008		
Emissions-CO (g/s)														
Highway					1.379	0.337								
Suburban									0.071	0.046	0.020			
Urban											0.021	0.025		
Emissions-NO_x (g/s)														
Highway					0.014	0.011								
Suburban									0.020	0.011	0.010			
Urban											0.010	0.010		
Emissions-CO_2 (g/s)														
Highway					7.925	6.839								
Suburban									4.147	3.385	2.841			
Urban											2.781	2.248		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							3.788	2.760	1.272	1.053	0.900	0.784	0.649	0.604
Suburban												0.792	0.637	0.590
Urban													0.609	0.543
Emissions-HC (g/s)														
Highway							0.059	0.034	0.018	0.005	0.006	0.007	0.005	0.005
Suburban												0.007	0.005	0.005
Urban													0.006	0.005
Emissions-CO (g/s)														
Highway							1.652	0.785	0.059	0.038	0.018	0.018	0.014	0.012
Suburban												0.019	0.014	0.014
Urban													0.017	0.014
Emissions-NO_x (g/s)														
Highway							0.019	0.016	0.020	0.009	0.009	0.008	0.006	0.005
Suburban												0.008	0.006	0.006
Urban													0.007	0.006
Emissions-CO_2 (g/s)														
Highway							8.924	7.185	3.791	3.174	2.733	2.372	1.966	1.833
Suburban												2.394	1.931	1.783
Urban													1.837	1.635

Based on Mileage

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	193.187	175.478	161.577	183.223										
Suburban						262.867	282.204	271.731						
Urban								216.646	188.138	192.427				
Emissions-HC (g/mile)														
Highway	0.320	0.302	0.266	0.634										
Suburban						3.679	2.340	1.745						
Urban								0.665	0.851	1.067				
Emissions-CO (g/mile)														
Highway	4.373	3.413	2.097	6.086										
Suburban						103.148	70.296	41.815						
Urban								6.369	10.320	6.427				
Emissions-NO_x (g/mile)														
Highway	0.747	0.763	0.783	0.926										
Suburban						1.646	1.152	1.482						
Urban								1.477	1.724	1.867				
Emissions-CO_2 (g/mile)														
Highway	588.640	535.565	494.734	554.177										
Suburban						638.428	753.912	768.005						
Urban								656.843	562.276	580.773				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					250.914	203.266								
Suburban									182.644	180.048	192.693			
Urban											188.914	215.664		
Emissions-HC (g/mile)														
Highway					3.335	1.129								
Suburban									2.186	0.928	1.317			
Urban											1.474	2.400		
Emissions-CO (g/mile)														
Highway					104.488	28.546								
Suburban									9.255	7.280	4.094			
Urban											4.354	7.152		
Emissions-NO_x (g/mile)														
Highway					1.023	0.960								
Suburban									2.644	1.728	2.016			
Urban											2.057	2.784		
Emissions-CO_2 (g/mile)														
Highway					600.606	579.318								
Suburban									542.932	541.584	584.496			
Urban											572.023	647.472		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							363.688	305.677	166.484	168.413	185.211	225.720	311.600	870.240
Suburban												227.952	305.904	849.600
Urban													292.480	781.440
Emissions-HC (g/mile)														
Highway							5.664	3.757	2.411	0.813	1.217	1.896	2.560	6.600
Suburban												1.901	2.400	7.632
Urban													2.880	7.680
Emissions-CO (g/mile)														
Highway							158.608	86.963	7.724	6.133	3.789	5.208	6.720	17.760
Suburban												5.501	6.624	20.736
Urban													7.920	20.640
Emissions-NO_x (g/mile)														
Highway							1.848	1.800	2.651	1.507	1.851	2.232	2.840	7.200
Suburban												2.362	2.784	8.064
Urban													3.200	7.920
Emissions-CO_2 (g/mile)														
Highway							856.744	795.858	496.276	507.800	562.200	683.088	943.720	2639.760
Suburban												689.472	926.640	2568.096
Urban													881.760	2354.880

Table A-2-17: "Driving Segments" Vehicle Performance Matrices for Large Van (Automatic Transmission)

Based on Time

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	2.219	1.944	1.931	2.330										
Suburban						3.138	2.524	2.705						
Urban								2.074	1.420	1.220				
Emissions-HC (g/s)														
Highway	0.004	0.004	0.004	0.008										
Suburban						0.006	0.013	0.006						
Urban								0.006	0.006	0.007				
Emissions-CO (g/s)														
Highway	0.011	0.010	0.014	0.080										
Suburban						0.090	0.128	0.097						
Urban								0.068	0.026	0.034				
Emissions-NO_x (g/s)														
Highway	0.013	0.011	0.011	0.011										
Suburban						0.010	0.016	0.011						
Urban								0.013	0.015	0.014				
Emissions-CO_2 (g/s)														
Highway	6.821	5.974	5.929	7.046										
Suburban						9.531	7.553	8.180						
Urban								6.280	4.327	3.692				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					2.954	2.535								
Suburban									1.802	1.308	1.184			
Urban											1.045	0.895		
Emissions-HC (g/s)														
Highway					0.006	0.005								
Suburban									0.012	0.006	0.007			
Urban											0.007	0.009		
Emissions-CO (g/s)														
Highway					0.090	0.067								
Suburban									0.078	0.033	0.030			
Urban											0.030	0.030		
Emissions-NO_x (g/s)														
Highway					0.008	0.009								
Suburban									0.023	0.014	0.016			
Urban											0.013	0.013		
Emissions-CO_2 (g/s)														
Highway					8.961	7.707								
Suburban									5.405	3.969	3.589			
Urban											3.159	2.686		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							2.988	3.091	1.907	1.273	1.176	1.033	0.782	0.569
Suburban												1.027	0.750	0.555
Urban													0.693	0.510
Emissions-HC (g/s)														
Highway							0.023	0.005	0.015	0.006	0.007	0.009	0.007	0.004
Suburban												0.008	0.006	0.005
Urban													0.007	0.005
Emissions-CO (g/s)														
Highway							0.254	0.106	0.098	0.028	0.028	0.026	0.018	0.011
Suburban												0.025	0.017	0.013
Urban													0.020	0.013
Emissions-NO_x (g/s)														
Highway							0.020	0.008	0.025	0.013	0.015	0.012	0.008	0.005
Suburban												0.012	0.007	0.005
Urban													0.008	0.005
Emissions-CO_2 (g/s)														
Highway							8.759	9.362	5.690	3.869	3.567	3.120	2.368	1.728
Suburban												3.106	2.271	1.680
Urban													2.087	1.539

Based on Mileage

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	118.320	111.946	120.866	159.789										
Suburban						265.819	242.292	299.617						
Urban								229.772	185.913	195.147				
Emissions-HC (g/mile)														
Highway	0.213	0.202	0.219	0.531										
Suburban						0.484	1.212	0.678						
Urban								0.628	0.720	1.067				
Emissions-CO (g/mile)														
Highway	0.587	0.590	0.877	5.469										
Suburban						7.648	12.324	10.772						
Urban								7.569	3.447	5.493				
Emissions-NO_x (g/mile)														
Highway	0.693	0.619	0.673	0.737										
Suburban						0.871	1.548	1.218						
Urban								1.422	1.920	2.240				
Emissions-CO_2 (g/mile)														
Highway	363.760	344.117	371.191	483.137										
Suburban						807.295	725.088	906.120						
Urban								695.575	566.444	590.773				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					223.869	214.701								
Suburban									235.924	209.344	243.607			
Urban											214.937	257.712		
Emissions-HC (g/mile)														
Highway					0.467	0.409								
Suburban									1.610	0.992	1.522			
Urban											1.440	2.688		
Emissions-CO (g/mile)														
Highway					6.834	5.661								
Suburban									10.250	5.296	6.069			
Urban											6.137	8.736		
Emissions-NO_x (g/mile)														
Highway					0.581	0.791								
Suburban									3.063	2.256	3.189			
Urban											2.743	3.696		
Emissions-CO_2 (g/mile)														
Highway					679.162	652.828								
Suburban									707.524	635.072	738.206			
Urban											649.749	773.568		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							286.880	342.406	249.611	203.653	241.903	297.384	375.480	819.240
Suburban												295.690	359.856	799.488
Urban													332.480	734.640
Emissions-HC (g/mile)														
Highway							2.200	0.591	1.920	0.893	1.457	2.472	3.120	6.240
Suburban												2.275	2.880	7.200
Urban													3.360	7.200
Emissions-CO (g/mile)														
Highway							24.376	11.723	12.807	4.547	5.674	7.608	8.480	16.440
Suburban												7.229	8.112	19.152
Urban													9.440	18.960
Emissions-NO_x (g/mile)														
Highway							1.920	0.849	3.316	2.013	2.983	3.552	3.680	6.600
Suburban												3.542	3.504	7.344
Urban													3.920	7.200
Emissions-CO_2 (g/mile)														
Highway							840.864	1036.985	744.807	618.973	733.749	898.680	1136.800	2487.600
Suburban												894.586	1089.840	2419.200
Urban													1001.840	2216.160

Table A-2-18: "Driving Segments" Vehicle Performance Matrices for Large Van (Manual Transmission)

Based on Time

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	3.190	2.504	2.131	2.293										
Suburban						2.810	2.972	2.417						
Urban								2.052	1.404	1.232				
Emissions-HC (g/s)														
Highway	0.006	0.004	0.004	0.009										
Suburban						0.005	0.006	0.006						
Urban								0.006	0.007	0.007				
Emissions-CO (g/s)														
Highway	0.078	0.045	0.026	0.085										
Suburban						0.064	0.095	0.083						
Urban								0.070	0.069	0.037				
Emissions-NO_x (g/s)														
Highway	0.011	0.011	0.011	0.012										
Suburban						0.011	0.009	0.011						
Urban								0.013	0.014	0.011				
Emissions-CO_2 (g/s)														
Highway	9.712	7.647	6.528	6.918										
Suburban						8.560	9.010	7.315						
Urban								6.206	4.207	3.724				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					3.066	2.280								
Suburban									1.347	1.151	0.935			
Urban											0.918	0.747		
Emissions-HC (g/s)														
Highway					0.007	0.005								
Suburban									0.017	0.006	0.007			
Urban											0.007	0.008		
Emissions-CO (g/s)														
Highway					0.090	0.051								
Suburban									0.064	0.030	0.021			
Urban											0.022	0.025		
Emissions-NO_x (g/s)														
Highway					0.008	0.010								
Suburban									0.023	0.011	0.010			
Urban											0.011	0.010		
Emissions-CO_2 (g/s)														
Highway					9.305	6.945								
Suburban									4.010	3.488	2.835			
Urban											2.779	2.244		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							3.886	2.435	1.224	1.074	0.899	0.781	0.650	0.607
Suburban												0.789	0.639	0.592
Urban													0.612	0.545
Emissions-HC (g/s)														
Highway							0.015	0.011	0.018	0.005	0.006	0.007	0.005	0.005
Suburban												0.007	0.005	0.005
Urban													0.006	0.005
Emissions-CO (g/s)														
Highway							0.150	0.072	0.054	0.025	0.019	0.018	0.015	0.013
Suburban												0.019	0.014	0.015
Urban													0.017	0.015
Emissions-NO_x (g/s)														
Highway							0.016	0.014	0.023	0.010	0.010	0.008	0.006	0.005
Suburban												0.008	0.006	0.006
Urban													0.007	0.006
Emissions-CO_2 (g/s)														
Highway							11.716	7.373	3.650	3.260	2.728	2.364	1.969	1.839
Suburban												2.386	1.934	1.790
Urban													1.843	1.643

Based on Mileage

Velocity Pattern: Free Flow

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	170.120	144.202	133.419	157.200										
Suburban						238.048	285.312	267.757						
Urban								227.262	183.775	197.040				
Emissions-HC (g/mile)														
Highway	0.293	0.245	0.250	0.600										
Suburban						0.460	0.540	0.678						
Urban								0.683	0.851	1.067				
Emissions-CO (g/mile)														
Highway	4.147	2.592	1.597	5.846										
Suburban						5.457	9.132	9.194						
Urban								7.735	9.055	5.867				
Emissions-NO_x (g/mile)														
Highway	0.587	0.605	0.657	0.823										
Suburban						0.932	0.864	1.260						
Urban								1.422	1.767	1.813				
Emissions-CO_2 (g/mile)														
Highway	517.973	440.453	408.710	474.377										
Suburban						725.070	864.960	810.222						
Urban								687.415	550.735	595.813				

Velocity Pattern: Speed Up/Slow Down

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					232.333	193.101								
Suburban									176.361	184.080	192.384			
Urban											188.914	215.136		
Emissions-HC (g/mile)														
Highway					0.493	0.395								
Suburban									2.173	0.912	1.399			
Urban											1.509	2.352		
Emissions-CO (g/mile)														
Highway					6.796	4.320								
Suburban									8.391	4.720	4.217			
Urban											4.491	7.056		
Emissions-NO_x (g/mile)														
Highway					0.619	0.805								
Suburban									2.945	1.760	2.119			
Urban											2.160	2.736		
Emissions-CO_2 (g/mile)														
Highway					705.183	588.296								
Suburban									524.893	558.128	583.221			
Urban											571.749	646.176		

Velocity Pattern: Stop and Go

Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							373.008	269.732	160.255	171.773	184.989	225.048	312.120	873.360
Suburban												227.146	306.480	852.768
Urban													293.520	785.040
Emissions-HC (g/mile)														
Highway							1.464	1.191	2.389	0.800	1.303	1.896	2.560	6.720
Suburban												1.901	2.400	7.776
Urban													2.880	7.680
Emissions-CO (g/mile)														
Highway							14.368	7.985	7.004	4.000	3.926	5.256	6.960	18.000
Suburban												5.530	6.816	21.024
Urban													8.160	20.880
Emissions-NO_x (g/mile)														
Highway							1.496	1.551	2.989	1.533	1.954	2.256	2.880	7.320
Suburban												2.390	2.832	8.064
Urban													3.280	7.920
Emissions-CO_2 (g/mile)														
Highway							1124.720	816.674	477.796	521.587	561.086	680.952	944.920	2648.760
Suburban												687.024	928.128	2576.880
Urban													884.560	2365.200

Table A-2-19: "Driving Segments" Vehicle Performance Matrices for SUV (Automatic Transmission)

Based on Time

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	2.517	2.290	2.168	2.165										
Suburban						2.752	2.276	2.165						
Urban								1.713	1.413	1.228				
Emissions-HC (g/s)														
Highway	0.005	0.005	0.005	0.012										
Suburban						0.039	0.018	0.016						
Urban								0.007	0.007	0.007				
Emissions-CO (g/s)														
Highway	0.017	0.012	0.016	0.051										
Suburban						0.104	0.102	0.083						
Urban								0.027	0.026	0.031				
Emissions-NO_x (g/s)														
Highway	0.017	0.016	0.015	0.024										
Suburban						0.057	0.026	0.025						
Urban								0.017	0.017	0.014				
Emissions-CO_2 (g/s)														
Highway	7.729	7.038	6.657	6.569										
Suburban						8.219	6.815	6.505						
Urban								5.227	4.302	3.723				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					2.226	2.050								
Suburban									2.124	1.722	1.369			
Urban											1.083	0.908		
Emissions-HC (g/s)														
Highway					0.033	0.012								
Suburban									0.030	0.008	0.011			
Urban											0.009	0.011		
Emissions-CO (g/s)														
Highway					0.100	0.030								
Suburban									0.247	0.033	0.043			
Urban											0.032	0.030		
Emissions-NO_x (g/s)														
Highway					0.051	0.025								
Suburban									0.039	0.019	0.021			
Urban											0.014	0.013		
Emissions-CO_2 (g/s)														
Highway					6.617	6.247								
Suburban									6.080	5.241	4.129			
Urban											3.267	2.724		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							3.257	3.011	2.439	1.879	1.469	1.174	0.881	0.642
Suburban												1.092	0.826	0.628
Urban													0.729	0.590
Emissions-HC (g/s)														
Highway							0.032	0.027	0.039	0.008	0.012	0.012	0.008	0.006
Suburban												0.010	0.007	0.006
Urban													0.008	0.007
Emissions-CO (g/s)														
Highway							0.201	0.149	0.340	0.029	0.046	0.035	0.023	0.014
Suburban												0.031	0.021	0.017
Urban													0.022	0.017
Emissions-NO_x (g/s)														
Highway							0.035	0.031	0.045	0.019	0.025	0.017	0.010	0.006
Suburban												0.015	0.009	0.007
Urban													0.009	0.007
Emissions-CO_2 (g/s)														
Highway							9.647	8.983	6.881	5.732	4.429	3.536	2.660	1.946
Suburban												3.292	2.496	1.896
Urban													2.193	1.775

Based on Mileage

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	134.227	131.904	135.751	148.423										
Suburban						233.147	218.520	239.760						
Urban								189.785	184.975	196.533				
Emissions-HC (g/mile)														
Highway	0.280	0.288	0.282	0.789										
Suburban						3.291	1.680	1.758						
Urban								0.757	0.938	1.147				
Emissions-CO (g/mile)														
Highway	0.880	0.706	0.986	3.463										
Suburban						8.822	9.804	9.222						
Urban								2.991	3.338	4.987				
Emissions-NO_x (g/mile)														
Highway	0.907	0.907	0.939	1.663										
Suburban						4.804	2.460	2.742						
Urban								1.883	2.160	2.293				
Emissions-CO_2 (g/mile)														
Highway	412.213	405.389	416.786	450.411										
Suburban						696.186	654.240	720.526						
Urban								579.028	563.149	595.627				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					168.695	173.633								
Suburban									278.012	275.568	281.705			
Urban											222.823	261.456		
Emissions-HC (g/mile)														
Highway					2.463	1.016								
Suburban									3.914	1.328	2.181			
Urban											1.817	3.168		
Emissions-CO (g/mile)														
Highway					7.579	2.527								
Suburban									32.308	5.296	8.866			
Urban											6.583	8.544		
Emissions-NO_x (g/mile)														
Highway					3.827	2.118								
Suburban									5.040	3.040	4.341			
Urban											2.777	3.696		
Emissions-CO_2 (g/mile)														
Highway					501.524	529.129								
Suburban									795.953	838.624	849.333			
Urban											672.137	784.464		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							312.680	333.545	319.265	300.627	302.211	338.160	423.040	924.960
Suburban												314.381	396.432	904.320
Urban													350.000	849.840
Emissions-HC (g/mile)														
Highway							3.024	2.945	5.051	1.253	2.400	3.360	3.960	7.920
Suburban												2.938	3.456	9.072
Urban													3.760	9.360
Emissions-CO (g/mile)														
Highway							19.280	16.551	44.520	4.680	9.514	10.056	10.880	20.640
Suburban												8.842	9.936	23.904
Urban													10.400	24.480
Emissions-NO_x (g/mile)														
Highway							3.328	3.480	5.847	3.053	5.109	4.824	4.960	8.760
Suburban												4.262	4.368	9.504
Urban													4.320	9.600
Emissions-CO_2 (g/mile)														
Highway							926.064	995.086	900.753	917.187	911.006	1018.272	1277.000	2801.640
Suburban												948.010	1197.840	2729.952
Urban													1052.640	2555.520

Table A-2-20: "Driving Segments" Vehicle Performance Matrices for SUV (Manual Transmission)

Based on Time

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	2.927	2.494	1.928	1.947										
Suburban						2.528	1.955	1.896						
Urban								1.517	1.366	1.101				
Emissions-HC (g/s)														
Highway	0.006	0.005	0.005	0.013										
Suburban						0.010	0.021	0.017						
Urban								0.012	0.012	0.011				
Emissions-CO (g/s)														
Highway	0.023	0.025	0.014	0.035										
Suburban						0.042	0.068	0.093						
Urban								0.073	0.114	0.038				
Emissions-NO_x (g/s)														
Highway	0.020	0.016	0.013	0.019										
Suburban						0.023	0.035	0.025						
Urban								0.022	0.022	0.016				
Emissions-CO_2 (g/s)														
Highway	8.985	7.647	5.917	5.920										
Suburban						7.709	5.867	5.658						
Urban								4.534	4.002	3.306				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					2.067	1.839								
Suburban									1.888	1.335	1.061			
Urban											0.937	0.811		
Emissions-HC (g/s)														
Highway					0.016	0.009								
Suburban									0.022	0.012	0.015			
Urban											0.012	0.013		
Emissions-CO (g/s)														
Highway					0.044	0.027								
Suburban									0.115	0.042	0.050			
Urban											0.034	0.034		
Emissions-NO_x (g/s)														
Highway					0.024	0.021								
Suburban									0.029	0.017	0.021			
Urban											0.014	0.013		
Emissions-CO_2 (g/s)														
Highway					6.267	5.609								
Suburban									5.584	4.021	3.155			
Urban											2.802	2.413		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							2.197	2.238	2.022	1.312	1.105	0.953	0.759	0.680
Suburban												0.935	0.735	0.666
Urban													0.679	0.616
Emissions-HC (g/s)														
Highway							0.027	0.018	0.022	0.010	0.017	0.014	0.010	0.008
Suburban												0.013	0.009	0.009
Urban													0.010	0.010
Emissions-CO (g/s)														
Highway							0.071	0.081	0.096	0.036	0.066	0.041	0.028	0.021
Suburban												0.036	0.024	0.024
Urban													0.025	0.023
Emissions-NO_x (g/s)														
Highway							0.031	0.022	0.024	0.016	0.027	0.016	0.011	0.008
Suburban												0.015	0.009	0.009
Urban													0.009	0.008
Emissions-CO_2 (g/s)														
Highway							6.598	6.738	6.050	3.962	3.258	2.834	2.269	2.042
Suburban												2.793	2.205	1.993
Urban													2.028	1.840

Based on Mileage

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	156.107	143.669	120.710	133.526										
Suburban						214.136	187.656	209.991						
Urban								168.074	178.865	176.107				
Emissions-HC (g/mile)														
Highway	0.307	0.302	0.297	0.874										
Suburban						0.835	1.980	1.842						
Urban								1.329	1.615	1.787				
Emissions-CO (g/mile)														
Highway	1.213	1.411	0.877	2.366										
Suburban						3.594	6.528	10.302						
Urban								8.086	14.880	6.053				
Emissions-NO_x (g/mile)														
Highway	1.040	0.907	0.830	1.303										
Suburban						1.936	3.396	2.728						
Urban								2.474	2.858	2.533				
Emissions-CO_2 (g/mile)														
Highway	479.200	440.467	370.440	405.943										
Suburban						653.010	563.220	626.705						
Urban								502.246	523.920	528.987				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					156.682	155.802								
Suburban									247.209	213.616	218.345			
Urban											192.686	233.568		
Emissions-HC (g/mile)														
Highway					1.175	0.776								
Suburban									2.815	1.888	3.045			
Urban											2.469	3.648		
Emissions-CO (g/mile)														
Highway					3.335	2.301								
Suburban									15.107	6.784	10.286			
Urban											7.063	9.792		
Emissions-NO_x (g/mile)														
Highway					1.819	1.765								
Suburban									3.744	2.784	4.217			
Urban											2.949	3.600		
Emissions-CO_2 (g/mile)														
Highway					474.998	475.087								
Suburban									731.036	643.312	649.008			
Urban											576.480	694.848		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							210.952	247.865	264.676	209.853	227.314	274.368	364.440	978.480
Suburban												269.338	352.848	958.752
Urban													326.000	887.520
Emissions-HC (g/mile)														
Highway							2.544	2.003	2.836	1.653	3.497	4.056	4.920	11.880
Suburban												3.629	4.368	13.536
Urban													4.800	13.920
Emissions-CO (g/mile)														
Highway							6.768	8.926	12.611	5.827	13.509	11.928	13.520	30.360
Suburban												10.483	11.472	33.984
Urban													12.080	32.880
Emissions-NO_x (g/mile)														
Highway							2.976	2.391	3.142	2.480	5.469	4.632	5.080	11.280
Suburban												4.176	4.464	12.384
Urban													4.480	12.000
Emissions-CO_2 (g/mile)														
Highway							633.448	746.382	791.978	633.867	670.217	816.288	1089.280	2940.960
Suburban												804.298	1058.400	2870.496
Urban													973.360	2648.880

Table A-2-21: "Driving Segments" Vehicle Performance Matrices for Hybrid

Based on Time

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	1.423	1.253	1.076	1.071										
Suburban						1.094	0.885	0.799						
Urban								0.737	0.583	0.481				
Emissions-HC (g/s)														
Highway	0.004	0.004	0.004	0.008										
Suburban						0.019	0.009	0.008						
Urban								0.006	0.005	0.005				
Emissions-CO (g/s)														
Highway	0.006	0.005	0.005	0.014										
Suburban						0.030	0.014	0.013						
Urban								0.009	0.008	0.008				
Emissions-NO_x (g/s)														
Highway	0.004	0.004	0.003	0.005										
Suburban						0.009	0.005	0.005						
Urban								0.004	0.003	0.003				
Emissions-CO_2 (g/s)														
Highway	4.371	3.850	3.303	3.260										
Suburban						3.276	2.682	2.421						
Urban								2.244	1.771	1.458				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					1.000	0.884								
Suburban									0.717	0.578	0.495			
Urban											0.400	0.299		
Emissions-HC (g/s)														
Highway					0.018	0.008								
Suburban									0.012	0.005	0.007			
Urban											0.006	0.006		
Emissions-CO (g/s)														
Highway					0.030	0.012								
Suburban									0.021	0.009	0.011			
Urban											0.007	0.008		
Emissions-NO_x (g/s)														
Highway					0.008	0.004								
Suburban									0.006	0.003	0.004			
Urban											0.002	0.001		
Emissions-CO_2 (g/s)														
Highway					2.988	2.687								
Suburban									2.146	1.755	1.490			
Urban											1.207	0.894		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							0.942	0.856	0.756	0.608	0.531	0.444	0.249	0.109
Suburban												0.405	0.217	0.101
Urban													0.187	0.083
Emissions-HC (g/s)														
Highway							0.013	0.011	0.014	0.005	0.007	0.007	0.005	0.004
Suburban												0.006	0.004	0.004
Urban													0.005	0.005
Emissions-CO (g/s)														
Highway							0.015	0.013	0.023	0.008	0.014	0.010	0.005	0.003
Suburban												0.009	0.005	0.003
Urban													0.005	0.004
Emissions-NO_x (g/s)														
Highway							0.005	0.004	0.007	0.003	0.004	0.003	0.001	0.000
Suburban												0.002	0.001	0.000
Urban													0.001	0.000
Emissions-CO_2 (g/s)														
Highway							2.846	2.589	2.255	1.850	1.593	1.334	0.745	0.322
Suburban												1.219	0.649	0.295
Urban													0.556	0.238

Based on Mileage

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	75.867	72.173	67.336	73.406										
Suburban						92.692	84.960	88.463						
Urban								81.618	76.276	76.907				
Emissions-HC (g/mile)														
Highway	0.213	0.216	0.219	0.531										
Suburban						1.585	0.900	0.928						
Urban								0.609	0.655	0.800				
Emissions-CO (g/mile)														
Highway	0.307	0.302	0.297	0.943										
Suburban						2.517	1.368	1.440						
Urban								0.997	1.047	1.227				
Emissions-NO_x (g/mile)														
Highway	0.200	0.202	0.188	0.343										
Suburban						0.726	0.492	0.498						
Urban								0.406	0.393	0.400				
Emissions-CO_2 (g/mile)														
Highway	233.120	221.760	206.765	223.560										
Suburban						277.460	257.436	268.117						
Urban								248.603	231.884	233.280				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					75.802	74.852								
Suburban									93.901	92.464	101.870			
Urban											82.286	86.208		
Emissions-HC (g/mile)														
Highway					1.326	0.649								
Suburban									1.597	0.864	1.378			
Urban											1.131	1.776		
Emissions-CO (g/mile)														
Highway					2.236	0.988								
Suburban									2.684	1.408	2.345			
Urban											1.509	2.160		
Emissions-NO_x (g/mile)														
Highway					0.619	0.353								
Suburban									0.838	0.464	0.720			
Urban											0.411	0.384		
Emissions-CO_2 (g/mile)														
Highway					226.472	227.576								
Suburban									280.944	280.736	306.576			
Urban											248.229	257.424		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							90.432	94.791	98.935	97.267	109.149	127.968	119.400	156.720
Suburban												116.669	104.016	144.864
Urban													89.680	120.000
Emissions-HC (g/mile)														
Highway							1.200	1.191	1.865	0.800	1.526	2.040	2.280	5.040
Suburban												1.786	1.968	5.616
Urban													2.160	6.480
Emissions-CO (g/mile)														
Highway							1.480	1.477	2.978	1.253	2.966	2.952	2.560	4.320
Suburban												2.534	2.160	4.608
Urban													2.320	5.280
Emissions-NO_x (g/mile)														
Highway							0.456	0.443	0.905	0.440	0.909	0.744	0.400	0.000
Suburban												0.634	0.336	0.000
Urban													0.240	0.000
Emissions-CO_2 (g/mile)														
Highway							273.184	286.763	295.200	296.013	327.669	384.312	357.760	462.960
Suburban												350.928	311.712	424.368
Urban													266.800	343.200

Table A-2-22: "Driving Segments" Vehicle Performance Matrices for EV

Based on Time

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	0.600	0.470	0.354	0.354										
Suburban						0.415	0.329	0.293						
Urban								0.237	0.182	0.156				
Emissions-HC (g/s)														
Highway	0.001	0.001	0.001	0.001										
Suburban						0.001	0.001	0.001						
Urban								0.000	0.000	0.000				
Emissions-CO (g/s)														
Highway	0.060	0.047	0.035	0.036										
Suburban						0.042	0.033	0.029						
Urban								0.024	0.018	0.016				
Emissions-NO_x (g/s)														
Highway	0.011	0.009	0.007	0.006										
Suburban						0.007	0.006	0.005						
Urban								0.004	0.003	0.003				
Emissions-CO_2 (g/s)														
Highway	5.112	4.003	3.013	3.013										
Suburban						3.536	2.798	2.495						
Urban								2.020	1.545	1.329				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					0.356	0.304								
Suburban									0.285	0.223	0.165			
Urban											0.120	0.091		
Emissions-HC (g/s)														
Highway					0.001	0.001								
Suburban									0.000	0.000	0.000			
Urban											0.000	0.000		
Emissions-CO (g/s)														
Highway					0.036	0.031								
Suburban									0.029	0.022	0.017			
Urban											0.012	0.009		
Emissions-NO_x (g/s)														
Highway					0.007	0.006								
Suburban									0.005	0.004	0.003			
Urban											0.002	0.002		
Emissions-CO_2 (g/s)														
Highway					3.027	2.588								
Suburban									2.423	1.901	1.408			
Urban											1.021	0.772		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							0.405	0.403	0.308	0.234	0.192	0.123	0.072	0.023
Suburban												0.106	0.068	0.029
Urban													0.066	0.039
Emissions-HC (g/s)														
Highway							0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Suburban												0.000	0.000	0.000
Urban													0.000	0.000
Emissions-CO (g/s)														
Highway							0.041	0.040	0.031	0.023	0.019	0.012	0.007	0.002
Suburban												0.011	0.007	0.003
Urban													0.007	0.004
Emissions-NO_x (g/s)														
Highway							0.007	0.007	0.006	0.004	0.004	0.002	0.001	0.001
Suburban												0.002	0.001	0.001
Urban													0.001	0.001
Emissions-CO_2 (g/s)														
Highway							3.449	3.431	2.619	1.990	1.631	1.051	0.612	0.198
Suburban												0.907	0.582	0.248
Urban													0.560	0.332

Based on Mileage

Velocity Pattern	Free Flow													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	32.020	27.083	22.158	24.270										
Suburban						35.184	31.553	32.461						
Urban								26.285	23.761	24.968				
Emissions-HC (g/mile)														
Highway	0.067	0.043	0.031	0.034										
Suburban						0.073	0.048	0.055						
Urban								0.037	0.044	0.027				
Emissions-CO (g/mile)														
Highway	3.200	2.707	2.207	2.434										
Suburban						3.521	3.168	3.254						
Urban								2.640	2.378	2.480				
Emissions-NO_x (g/mile)														
Highway	0.587	0.490	0.407	0.429										
Suburban						0.629	0.564	0.595						
Urban								0.480	0.436	0.453				
Emissions-CO_2 (g/mile)														
Highway	272.627	230.587	188.656	206.623										
Suburban						299.544	268.632	276.355						
Urban								223.772	202.298	212.560				

Velocity Pattern	Speed Up/Slow Down													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					26.947	25.744								
Suburban									37.255	35.731	34.024			
Urban											24.660	26.111		
Emissions-HC (g/mile)														
Highway					0.038	0.056								
Suburban									0.052	0.048	0.062			
Urban											0.034	0.000		
Emissions-CO (g/mile)														
Highway					2.703	2.584								
Suburban									3.731	3.568	3.394			
Urban											2.469	2.640		
Emissions-NO_x (g/mile)														
Highway					0.505	0.466								
Suburban									0.668	0.656	0.617			
Urban											0.446	0.528		
Emissions-CO_2 (g/mile)														
Highway					229.427	219.176								
Suburban									317.193	304.208	289.687			
Urban											209.931	222.288		

Velocity Pattern	Stop and Go													
Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							38.891	44.645	40.272	37.393	39.415	35.561	34.527	33.424
Suburban												30.670	32.791	41.964
Urban													31.581	56.048
Emissions-HC (g/mile)														
Highway							0.048	0.074	0.055	0.040	0.069	0.072	0.000	0.000
Suburban												0.058	0.000	0.000
Urban													0.000	0.000
Emissions-CO (g/mile)														
Highway							3.896	4.477	4.036	3.733	3.926	3.576	3.520	3.480
Suburban												3.082	3.312	4.320
Urban													3.200	5.760
Emissions-NO_x (g/mile)														
Highway							0.704	0.812	0.720	0.680	0.720	0.672	0.600	0.720
Suburban												0.605	0.576	0.864
Urban													0.560	0.960
Emissions-CO_2 (g/mile)														
Highway							331.120	380.095	342.873	318.360	335.589	302.736	293.920	284.640
Suburban												261.101	279.120	357.408
Urban													268.880	477.360

Table A-2-23: “Driving Segments” Vehicle Performance Matrices for FCV

Based on Time

Velocity Pattern: Free Flow Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway	0.733	0.660	0.635	0.606										
Suburban						0.678	0.548	0.493						
Urban								0.470	0.428	0.375				
Emissions-HC (g/s)														
Highway	0.005	0.004	0.004	0.003										
Suburban						0.004	0.003	0.003						
Urban								0.003	0.003	0.003				
Emissions-CO (g/s)														
Highway	0.005	0.005	0.005	0.004										
Suburban						0.005	0.004	0.003						
Urban								0.003	0.003	0.003				
Emissions-NO_x (g/s)														
Highway	0.013	0.012	0.011	0.011										
Suburban						0.012	0.009	0.008						
Urban								0.008	0.008	0.007				
Emissions-CO_2 (g/s)														
Highway	4.166	3.749	3.606	3.442										
Suburban						3.844	3.111	2.796						
Urban								2.668	2.427	2.127				

Velocity Pattern: Speed Up/Slow Down Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway					0.600	0.577								
Suburban									0.445	0.410	0.357			
Urban											0.320	0.266		
Emissions-HC (g/s)														
Highway					0.004	0.003								
Suburban									0.003	0.003	0.002			
Urban											0.002	0.002		
Emissions-CO (g/s)														
Highway					0.004	0.004								
Suburban									0.003	0.003	0.003			
Urban											0.002	0.002		
Emissions-NO_x (g/s)														
Highway					0.011	0.010								
Suburban									0.008	0.007	0.006			
Urban											0.006	0.005		
Emissions-CO_2 (g/s)														
Highway					3.406	3.272								
Suburban									2.525	2.327	2.029			
Urban											1.818	1.508		

Velocity Pattern: Stop and Go Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/s)														
Highway							0.545	0.512	0.440	0.415	0.370	0.318	0.289	0.269
Suburban												0.305	0.275	0.256
Urban													0.249	0.237
Emissions-HC (g/s)														
Highway							0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002
Suburban												0.002	0.002	0.001
Urban													0.002	0.001
Emissions-CO (g/s)														
Highway							0.004	0.003	0.003	0.003	0.003	0.002	0.002	0.002
Suburban												0.002	0.002	0.002
Urban													0.002	0.002
Emissions-NO_x (g/s)														
Highway							0.009	0.009	0.008	0.007	0.006	0.006	0.005	0.005
Suburban												0.005	0.005	0.004
Urban													0.004	0.004
Emissions-CO_2 (g/s)														
Highway							3.094	2.906	2.497	2.357	2.099	1.805	1.642	1.528
Suburban												1.728	1.560	1.453
Urban													1.412	1.342

Based on Mileage

Velocity Pattern: Free Flow Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway	39.107	38.016	39.749	41.573										
Suburban						57.409	52.644	54.560						
Urban								52.036	56.017	59.981				
Emissions-HC (g/mile)														
Highway	0.240	0.216	0.235	0.223										
Suburban						0.339	0.312	0.332						
Urban								0.314	0.349	0.400				
Emissions-CO (g/mile)														
Highway	0.267	0.274	0.282	0.291										
Suburban						0.411	0.348	0.360						
Urban								0.351	0.371	0.400				
Emissions-NO_x (g/mile)														
Highway	0.680	0.662	0.689	0.720										
Suburban						0.980	0.900	0.928						
Urban								0.886	0.982	1.040				
Emissions-CO_2 (g/mile)														
Highway	222.160	215.928	225.767	236.006										
Suburban						325.646	298.692	309.725						
Urban								295.514	317.695	340.347				

Velocity Pattern: Speed Up/Slow Down Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway					45.474	48.854								
Suburban									58.270	65.593	73.540			
Urban											65.924	76.487		
Emissions-HC (g/mile)														
Highway					0.278	0.282								
Suburban									0.367	0.432	0.432			
Urban											0.411	0.480		
Emissions-CO (g/mile)														
Highway					0.328	0.353								
Suburban									0.406	0.432	0.535			
Urban											0.480	0.576		
Emissions-NO_x (g/mile)														
Highway					0.796	0.833								
Suburban									1.021	1.136	1.255			
Urban											1.131	1.392		
Emissions-CO_2 (g/mile)														
Highway					258.101	277.129								
Suburban									330.532	372.352	417.394			
Urban											373.886	434.208		

Velocity Pattern: Stop and Go Ave. Speed (mph)	67.5	62.5	57.5	52.5	47.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
Fuel Consumption (g/mile)														
Highway							52.331	56.698	57.630	66.419	76.066	91.691	138.865	387.795
Suburban												87.766	132.078	368.908
Urban													119.665	340.912
Emissions-HC (g/mile)														
Highway							0.312	0.342	0.360	0.427	0.446	0.600	0.840	2.160
Suburban												0.576	0.816	2.016
Urban													0.720	1.680
Emissions-CO (g/mile)														
Highway							0.352	0.369	0.404	0.440	0.566	0.672	1.000	2.880
Suburban												0.634	0.912	2.736
Urban													0.800	2.640
Emissions-NO_x (g/mile)														
Highway							0.888	0.969	1.004	1.147	1.303	1.608	2.400	6.720
Suburban												1.555	2.304	6.336
Urban													2.080	5.760
Emissions-CO_2 (g/mile)														
Highway							297.016	321.858	326.858	377.080	431.794	519.696	787.960	2200.920
Suburban												497.693	748.848	2091.888
Urban													677.920	1932.960

Table A-4-1: New Sales and Sale Shares for Passenger Cars (1976-2030)

	Two-seater		Subcompact		Compact		Midsize		Large	
YEAR	units	%	units	%	units	%	units	%	units	%
1976	199,716	1.7	2,625,929	21.7	2,839,603	23.5	1,815,505	15.0	2,206,102	18.2
1977	221,444	1.7	2,868,197	21.9	2,840,635	21.7	2,033,250	15.6	2,603,017	19.9
1978	214,146	1.5	3,054,281	21.8	1,684,964	12.0	3,664,381	26.1	2,472,877	17.6
1979	231,215	1.7	3,902,868	28.7	905,786	6.7	3,651,304	26.9	2,097,084	15.4
1980	215,964	1.9	3,869,826	34.2	599,423	5.3	3,073,103	27.2	1,336,190	11.8
1981	242,961	2.2	3,224,276	29.8	1,191,194	11.0	3,113,806	28.8	1,107,627	10.2
1982	202,929	2.1	2,626,188	26.8	1,300,372	13.3	2,533,121	25.9	995,561	10.2
1983	203,442	1.8	2,584,394	22.6	1,927,460	16.8	2,779,178	24.3	1,275,939	11.1
1984	328,968	2.4	2,552,297	18.5	2,768,056	20.0	3,059,647	22.1	1,502,097	10.9
1985	373,697	2.5	2,434,634	16.0	3,526,118	23.2	3,117,817	20.5	1,516,249	10.0
1986	277,768	1.8	2,678,430	17.1	3,688,647	23.6	2,985,835	19.1	1,467,077	9.4
1987	245,852	1.6	2,167,070	14.5	4,071,427	27.2	2,586,303	17.3	1,301,363	8.7
1988	186,127	1.2	2,067,539	13.7	4,199,638	27.8	2,550,964	16.9	1,368,717	9.1
1989	158,884	1.1	1,984,062	13.3	3,690,419	24.7	2,939,948	19.7	1,400,514	9.4
1990	170,465	1.2	2,106,924	15.3	3,156,481	23.0	2,511,503	18.3	1,279,092	9.3
1991	134,890	1.1	2,352,583	18.9	2,425,398	19.5	2,305,773	18.6	1,161,319	9.3
1992	83,192	0.7	2,181,985	17.5	2,451,498	19.6	2,249,553	18.0	1,140,775	9.1
1993	70,480	0.5	2,029,237	15.1	2,655,378	19.8	2,445,842	18.2	1,186,991	8.8
1994	67,020	0.5	2,072,478	14.2	3,077,203	21.0	2,359,898	16.1	1,339,863	9.2
1995	53,045	0.4	1,562,961	10.7	3,289,735	22.4	2,498,521	17.0	1,320,608	9.0
1996	62,231	0.4	1,349,515	9.1	3,492,957	23.5	2,487,880	16.7	1,259,266	8.5
1997	80,921	0.5	1,549,569	10.5	2,937,064	19.9	2,531,196	17.1	1,162,290	7.9
1998	101,023	0.7	1,503,392	9.9	2,309,330	15.2	3,106,787	20.4	1,050,405	6.9
1999	103,248	0.6	1,635,386	9.8	2,367,048	14.2	3,359,492	20.2	1,180,739	7.1
2000	122,259	0.7	1,808,595	10.5	2,397,813	13.9	3,352,198	19.4	1,297,237	7.5
2001	118,097	0.7	955,493	5.9	3,058,389	18.7	2,669,116	16.3	1,506,890	9.2
2002	134,187	0.8	690,237	4.1	3,217,151	18.9	2,917,527	17.2	1,377,357	8.1
2003	165,322	1.0	539,311	3.3	3,018,407	18.5	2,624,346	16.1	1,350,670	8.3
2004	160,644	1.0	425,924	2.6	2,973,097	18.1	2,617,424	15.9	1,283,904	7.8
2005	155,983	0.9	313,626	1.9	2,927,663	17.7	2,610,051	15.7	1,217,573	7.3
2006	151,339	0.9	202,466	1.2	2,882,113	17.2	2,602,220	15.6	1,151,701	6.9
2007	146,715	0.9	92,491	0.5	2,836,453	16.8	2,593,922	15.4	1,086,313	6.4
2008	142,111	0.8	93,231	0.5	2,790,691	16.4	2,585,148	15.2	1,021,433	6.0
2009	137,529	0.8	93,977	0.5	2,744,835	16.0	2,575,891	15.1	957,087	5.6
2010	132,971	0.8	94,729	0.5	2,698,893	15.6	2,566,141	14.9	893,300	5.2
2011	128,438	0.7	95,487	0.5	2,652,873	15.3	2,555,890	14.7	830,099	4.8
2012	123,931	0.7	96,251	0.5	2,606,784	14.9	2,545,129	14.5	767,511	4.4
2013	119,453	0.7	97,021	0.5	2,560,634	14.5	2,533,849	14.3	705,562	4.0
2014	115,004	0.6	97,797	0.5	2,514,432	14.1	2,522,041	14.2	644,281	3.6
2015	110,587	0.6	98,579	0.5	2,468,187	13.7	2,509,696	14.0	583,697	3.3
2016	106,202	0.6	99,368	0.5	2,421,908	13.4	2,496,805	13.8	523,837	2.9
2017	101,853	0.6	100,163	0.5	2,375,603	13.0	2,483,357	13.6	464,731	2.5
2018	97,540	0.5	100,964	0.5	2,329,284	12.7	2,469,344	13.4	406,409	2.2
2019	93,266	0.5	101,772	0.5	2,282,959	12.3	2,454,755	13.2	348,902	1.9
2020	89,031	0.5	102,586	0.5	2,236,639	12.0	2,439,581	13.1	292,241	1.6
2021	84,839	0.5	103,407	0.5	2,190,334	11.6	2,423,812	12.9	236,456	1.3
2022	80,690	0.4	104,234	0.5	2,144,054	11.3	2,407,438	12.7	181,581	1.0
2023	76,587	0.4	105,068	0.5	2,097,810	11.0	2,390,449	12.5	127,647	0.7
2024	72,532	0.4	105,908	0.5	2,051,612	10.6	2,372,833	12.3	74,689	0.4
2025	68,526	0.4	106,756	0.5	2,005,472	10.3	2,354,582	12.1	22,739	0.1
2026	64,572	0.3	107,610	0.5	1,959,402	10.0	2,335,683	11.9	22,921	0.1
2027	60,671	0.3	108,471	0.5	1,913,412	9.7	2,316,126	11.7	23,104	0.1
2028	56,826	0.3	109,338	0.5	1,867,514	9.4	2,295,900	11.5	23,289	0.1
2029	53,039	0.3	110,213	0.5	1,821,721	9.1	2,274,995	11.3	23,475	0.1
2030	49,313	0.2	111,095	0.5	1,776,045	8.8	2,253,398	11.1	23,663	0.1

Table A-4-2: New Sales and Sale Shares for Light Trucks (1976-2030)

	Small pickup		Large pickup		Small van		Large van		SUV	
YEAR	units	%	units	%	units	%	units	%	units	%
1976	170,351	1.4	1,586,020	13.1	18,651	0.2	574,745	4.8	59,991	0.5
1977	275,217	2.1	1,719,799	13.2	24,547	0.2	415,733	3.2	71,959	0.6
1978	308,790	2.2	1,886,782	13.4	24,755	0.2	670,453	4.8	55,679	0.4
1979	451,548	3.3	1,635,745	12.0	18,153	0.1	580,883	4.3	114,834	0.8
1980	516,412	4.6	1,115,248	9.9	13,649	0.1	328,065	2.9	243,163	2.1
1981	472,611	4.4	967,242	8.9	11,007	0.1	327,730	3.0	156,826	1.5
1982	579,263	5.9	1,000,772	10.2	11,964	0.1	379,110	3.9	161,731	1.7
1983	894,432	7.8	958,408	8.4	13,716	0.1	484,349	4.2	336,394	2.9
1984	857,804	6.2	1,375,948	10.0	222,798	1.6	545,595	3.9	610,789	4.4
1985	863,584	5.7	1,690,931	11.1	437,660	2.9	536,242	3.5	706,948	4.6
1986	981,857	6.3	1,593,512	10.2	640,936	4.1	510,558	3.3	808,025	5.2
1987	971,882	6.5	1,542,591	10.3	733,504	4.9	473,268	3.2	858,791	5.7
1988	1,026,551	6.8	1,453,255	9.6	851,384	5.6	486,981	3.2	924,829	6.1
1989	877,839	5.9	1,580,916	10.6	859,311	5.8	471,762	3.2	976,214	6.5
1990	1,135,727	8.3	1,116,490	8.1	1,012,141	7.4	319,429	2.3	930,838	6.8
1991	1,003,514	8.1	933,867	7.5	948,056	7.6	248,426	2.0	914,328	7.4
1992	1,001,253	8.0	1,037,691	8.3	1,037,868	8.3	280,506	2.2	1,035,133	8.3
1993	1,093,361	8.1	1,116,915	8.3	1,203,058	8.9	314,836	2.3	1,327,507	9.9
1994	1,159,697	7.9	1,404,849	9.6	1,350,472	9.2	321,198	2.2	1,488,185	10.2
1995	1,067,764	7.3	1,472,885	10.0	1,330,586	9.1	327,586	2.2	1,735,045	11.8
1996	1,009,626	6.8	1,607,483	10.8	1,306,657	8.8	293,119	2.0	2,019,976	13.6
1997	977,713	6.6	1,594,265	10.8	1,297,942	8.8	304,397	2.1	2,352,399	15.9
1998	891,011	5.9	1,947,002	12.8	1,273,259	8.4	331,240	2.2	2,695,138	17.7
1999	1,110,840	6.7	2,021,857	12.1	1,372,154	8.2	364,057	2.2	3,132,847	18.8
2000	1,071,730	6.2	1,968,710	11.4	1,272,070	7.4	368,820	2.1	3,625,623	21.0
2001	819,033	5.0	1,987,833	12.2	1,141,109	7.0	323,806	2.0	3,747,737	23.0
2002	761,802	4.5	2,209,671	13.0	1,165,202	6.9	349,706	2.1	4,186,698	24.6
2003	744,040	4.6	2,077,330	12.7	1,065,875	6.5	321,627	2.0	4,408,542	27.0
2004	759,192	4.6	2,064,449	12.6	1,098,783	6.7	303,272	1.8	4,545,505	27.6
2005	774,037	4.7	2,051,289	12.4	1,131,131	6.8	285,047	1.7	4,680,143	28.2
2006	788,562	4.7	2,037,848	12.2	1,162,901	7.0	266,958	1.6	4,812,377	28.8
2007	802,760	4.8	2,024,121	12.0	1,194,071	7.1	249,013	1.5	4,942,124	29.3
2008	816,619	4.8	2,010,107	11.8	1,224,623	7.2	231,218	1.4	4,959,824	29.2
2009	830,128	4.9	1,995,801	11.7	1,254,535	7.3	213,580	1.2	4,976,153	29.1
2010	843,278	4.9	1,981,201	11.5	1,283,789	7.4	196,107	1.1	4,991,076	28.9
2011	856,058	4.9	1,966,303	11.3	1,312,362	7.5	178,806	1.0	5,004,560	28.8
2012	868,455	5.0	1,951,103	11.1	1,340,233	7.6	161,685	0.9	5,016,569	28.6
2013	880,460	5.0	1,935,599	11.0	1,367,382	7.7	144,752	0.8	5,027,067	28.5
2014	892,061	5.0	1,919,787	10.8	1,393,784	7.8	128,015	0.7	5,036,020	28.3
2015	903,247	5.0	1,903,664	10.6	1,419,419	7.9	111,481	0.6	5,043,390	28.1
2016	914,005	5.1	1,887,226	10.4	1,444,263	8.0	95,158	0.5	5,049,140	27.9
2017	924,323	5.1	1,870,470	10.3	1,468,294	8.0	79,056	0.4	5,053,233	27.7
2018	934,190	5.1	1,853,392	10.1	1,491,487	8.1	63,182	0.3	5,055,630	27.5
2019	943,594	5.1	1,835,989	9.9	1,513,819	8.2	47,545	0.3	5,056,292	27.3
2020	952,520	5.1	1,818,256	9.7	1,535,265	8.2	32,154	0.2	5,055,180	27.1
2021	960,958	5.1	1,800,192	9.6	1,555,801	8.3	17,018	0.1	5,052,254	26.8
2022	968,894	5.1	1,781,791	9.4	1,575,401	8.3	17,154	0.1	5,032,464	26.5
2023	976,314	5.1	1,763,050	9.2	1,594,039	8.3	17,291	0.1	5,011,050	26.2
2024	983,205	5.1	1,743,966	9.0	1,611,691	8.4	17,430	0.1	4,987,980	25.9
2025	989,554	5.1	1,724,535	8.9	1,628,328	8.4	17,569	0.1	4,963,219	25.5
2026	995,347	5.1	1,704,752	8.7	1,643,925	8.4	17,710	0.1	4,885,647	24.9
2027	1,000,570	5.1	1,684,615	8.5	1,658,454	8.4	17,851	0.1	4,807,394	24.3
2028	1,005,208	5.0	1,664,119	8.4	1,671,887	8.4	17,994	0.1	4,728,461	23.7
2029	1,009,247	5.0	1,643,261	8.2	1,684,196	8.4	18,138	0.1	4,648,850	23.2
2030	1,012,673	5.0	1,622,036	8.0	1,695,352	8.4	18,283	0.1	4,568,563	22.6

Table A-4-3: New Sales and Sale Shares for New Technologies (1976-2030)

	Hybrid		EV		FCV	
YEAR	units	%	units	%	units	%
1976	0	0.0	0	0.0	0	0.0
1977	0	0.0	0	0.0	0	0.0
1978	0	0.0	0	0.0	0	0.0
1979	0	0.0	0	0.0	0	0.0
1980	0	0.0	0	0.0	0	0.0
1981	0	0.0	0	0.0	0	0.0
1982	0	0.0	0	0.0	0	0.0
1983	0	0.0	0	0.0	0	0.0
1984	0	0.0	0	0.0	0	0.0
1985	0	0.0	0	0.0	0	0.0
1986	0	0.0	0	0.0	0	0.0
1987	0	0.0	0	0.0	0	0.0
1988	0	0.0	0	0.0	0	0.0
1989	0	0.0	0	0.0	0	0.0
1990	0	0.0	0	0.0	0	0.0
1991	0	0.0	0	0.0	0	0.0
1992	0	0.0	0	0.0	0	0.0
1993	0	0.0	0	0.0	0	0.0
1994	0	0.0	0	0.0	0	0.0
1995	0	0.0	0	0.0	0	0.0
1996	0	0.0	0	0.0	0	0.0
1997	0	0.0	0	0.0	0	0.0
1998	0	0.0	0	0.0	0	0.0
1999	0	0.0	0	0.0	0	0.0
2000	0	0.0	0	0.0	0	0.0
2001	0	0.0	0	0.0	0	0.0
2002	0	0.0	0	0.0	0	0.0
2003	0	0.0	0	0.0	0	0.0
2004	164,460	1.0	32,892	0.2	16,446	0.1
2005	331,551	2.0	66,310	0.4	33,155	0.2
2006	501,305	3.0	100,261	0.6	50,131	0.3
2007	673,755	4.0	134,751	0.8	67,375	0.4
2008	848,931	5.0	169,786	1.0	84,893	0.5
2009	1,026,867	6.0	205,373	1.2	102,687	0.6
2010	1,207,595	7.0	241,519	1.4	120,760	0.7
2011	1,391,150	8.0	278,230	1.6	139,115	0.8
2012	1,577,564	9.0	315,513	1.8	157,756	0.9
2013	1,766,871	10.0	353,374	2.0	176,687	1.0
2014	1,959,107	11.0	391,821	2.2	195,911	1.1
2015	2,154,305	12.0	430,861	2.4	215,431	1.2
2016	2,352,501	13.0	470,500	2.6	235,250	1.3
2017	2,553,731	14.0	510,746	2.8	255,373	1.4
2018	2,758,029	15.0	551,606	3.0	275,803	1.5
2019	2,965,433	16.0	593,087	3.2	296,543	1.6
2020	3,175,979	17.0	635,196	3.4	317,598	1.7
2021	3,389,703	18.0	677,941	3.6	338,970	1.8
2022	3,606,644	19.0	721,329	3.8	360,664	1.9
2023	3,826,839	20.0	765,368	4.0	382,684	2.0
2024	4,050,327	21.0	810,065	4.2	405,033	2.1
2025	4,277,145	22.0	855,429	4.4	427,715	2.2
2026	4,507,333	23.0	901,467	4.6	450,733	2.3
2027	4,740,931	24.0	948,186	4.8	474,093	2.4
2028	4,977,977	25.0	995,595	5.0	497,798	2.5
2029	5,218,513	26.0	1,043,703	5.2	521,851	2.6
2030	5,462,579	27.0	1,092,516	5.4	546,258	2.7

Table A-4-4: New Sales and Sale Shares for Light-Duty Vehicles (1976-2030)

	CARS		LIGHT TRUCKS		NEW TECH		LDV TOTAL	
YEAR	units	%	units	%	units	%	units	%
1976	9,686,855	80.1	2,409,758	19.9	0	0.0	12,096,613	100.0
1977	10,566,543	80.8	2,507,255	19.2	0	0.0	13,073,798	100.0
1978	11,090,649	79.0	2,946,459	21.0	0	0.0	14,037,108	100.0
1979	10,788,257	79.4	2,801,163	20.6	0	0.0	13,589,420	100.0
1980	9,094,506	80.4	2,216,537	19.6	0	0.0	11,311,043	100.0
1981	8,879,864	82.1	1,935,416	17.9	0	0.0	10,815,280	100.0
1982	7,658,171	78.2	2,132,840	21.8	0	0.0	9,791,011	100.0
1983	8,770,413	76.5	2,687,299	23.5	0	0.0	11,457,712	100.0
1984	10,211,065	73.9	3,612,934	26.1	0	0.0	13,823,999	100.0
1985	10,968,515	72.1	4,235,365	27.9	0	0.0	15,203,880	100.0
1986	11,097,757	71.0	4,534,888	29.0	0	0.0	15,632,645	100.0
1987	10,372,015	69.4	4,580,036	30.6	0	0.0	14,952,051	100.0
1988	10,372,985	68.6	4,743,000	31.4	0	0.0	15,115,985	100.0
1989	10,173,827	68.1	4,766,042	31.9	0	0.0	14,939,869	100.0
1990	9,224,465	67.1	4,514,625	32.9	0	0.0	13,739,090	100.0
1991	8,379,963	67.4	4,048,191	32.6	0	0.0	12,428,154	100.0
1992	8,107,003	64.9	4,392,451	35.1	0	0.0	12,499,454	100.0
1993	8,387,928	62.4	5,055,677	37.6	0	0.0	13,443,605	100.0
1994	8,916,462	60.9	5,724,401	39.1	0	0.0	14,640,863	100.0
1995	8,724,870	59.5	5,933,866	40.5	0	0.0	14,658,736	100.0
1996	8,651,849	58.1	6,236,861	41.9	0	0.0	14,888,710	100.0
1997	8,261,040	55.9	6,526,716	44.1	0	0.0	14,787,756	100.0
1998	8,070,937	53.1	7,137,650	46.9	0	0.0	15,208,587	100.0
1999	8,645,913	51.9	8,001,755	48.1	0	0.0	16,647,668	100.0
2000	8,978,102	51.9	8,306,953	48.1	0	0.0	17,285,055	100.0
2001	8,307,985	50.9	8,019,518	49.1	0	0.0	16,327,503	100.0
2002	8,336,459	49.0	8,673,079	51.0	0	0.0	17,009,538	100.0
2003	7,698,056	47.2	8,617,414	52.8	0	0.0	16,315,470	100.0
2004	7,460,994	45.4	8,771,202	53.3	213,798	1.3	16,445,994	100.0
2005	7,224,897	43.6	8,921,648	53.8	431,017	2.6	16,577,562	100.0
2006	6,989,839	41.8	9,068,646	54.3	651,697	3.9	16,710,182	100.0
2007	6,755,894	40.1	9,212,089	54.7	875,881	5.2	16,843,864	100.0
2008	6,632,614	39.1	9,242,390	54.4	1,103,610	6.5	16,978,615	100.0
2009	6,509,319	38.0	9,270,198	54.2	1,334,927	7.8	17,114,443	100.0
2010	6,386,034	37.0	9,295,451	53.9	1,569,874	9.1	17,251,359	100.0
2011	6,262,787	36.0	9,318,088	53.6	1,808,494	10.4	17,389,370	100.0
2012	6,139,606	35.0	9,338,046	53.3	2,050,833	11.7	17,528,485	100.0
2013	6,016,519	34.1	9,355,261	52.9	2,296,933	13.0	17,668,713	100.0
2014	5,893,556	33.1	9,369,668	52.6	2,546,839	14.3	17,810,062	100.0
2015	5,770,746	32.1	9,381,201	52.3	2,800,597	15.6	17,952,543	100.0
2016	5,648,119	31.2	9,389,793	51.9	3,058,252	16.9	18,096,163	100.0
2017	5,525,707	30.3	9,395,376	51.5	3,319,850	18.2	18,240,933	100.0
2018	5,403,541	29.4	9,397,881	51.1	3,585,438	19.5	18,386,860	100.0
2019	5,281,654	28.5	9,397,238	50.7	3,855,063	20.8	18,533,955	100.0
2020	5,160,079	27.6	9,393,376	50.3	4,128,772	22.1	18,682,227	100.0
2021	5,038,848	26.8	9,386,222	49.8	4,406,614	23.4	18,831,684	100.0
2022	4,917,997	25.9	9,375,704	49.4	4,688,637	24.7	18,982,338	100.0
2023	4,797,560	25.1	9,361,745	48.9	4,974,891	26.0	19,134,197	100.0
2024	4,677,574	24.3	9,344,271	48.4	5,265,425	27.3	19,287,270	100.0
2025	4,558,074	23.4	9,323,205	48.0	5,560,289	28.6	19,441,568	100.0
2026	4,490,187	22.9	9,247,381	47.2	5,859,533	29.9	19,597,101	100.0
2027	4,421,784	22.4	9,168,884	46.4	6,163,210	31.2	19,753,878	100.0
2028	4,352,868	21.9	9,087,670	45.6	6,471,370	32.5	19,911,909	100.0
2029	4,283,444	21.3	9,003,693	44.9	6,784,067	33.8	20,071,204	100.0
2030	4,213,514	20.8	8,916,907	44.1	7,101,353	35.1	20,231,774	100.0

Table A-4-5: Survival Rates for Cars and New Tech (%)

		Vehicle Model							
		75 & before	*1970*	*1980*	*1990*	*2000*	*2010*	*2020*	*2030*
Vehicle	**1**	53.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Age	**2**	46.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
(year)	**3**	40.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	4	34.2	99.0	100.0	100.0	100.0	100.0	100.0	100.0
	5	28.7	94.1	96.3	100.0	100.0	100.0	100.0	100.0
	6	23.7	88.4	91.3	99.4	100.0	100.0	100.0	100.0
	7	19.3	82.0	85.7	96.3	100.0	100.0	100.0	100.0
	8	15.5	75.2	79.7	92.7	100.0	100.0	100.0	100.0
	9	12.3	68.1	73.3	88.7	99.0	99.0	99.0	99.0
	10	9.6	60.9	66.6	84.4	96.2	96.2	96.2	96.2
	11	7.4	53.8	60.0	79.8	92.8	92.8	92.8	92.8
	12	5.6	46.9	53.3	75.0	89.1	89.1	89.1	89.1
	13	4.2	40.3	46.9	70.0	84.9	84.9	84.9	84.9
	14	3.1	34.2	40.8	64.9	80.3	80.3	80.3	80.3
	15	2.2	28.7	35.1	59.7	75.2	75.2	75.2	75.2
	16	1.6	23.7	29.8	54.6	70.1	70.1	70.1	70.1
	17	1.1	19.3	25.0	49.5	64.6	64.6	64.6	64.6
	18	0.8	15.5	20.8	44.6	59.2	59.2	59.2	59.2
	19	0.5	12.3	17.0	39.9	53.7	53.7	53.7	53.7
	20	0.4	9.6	13.8	35.4	48.3	48.3	48.3	48.3
	21	0.0	7.4	11.0	31.1	43.0	43.0	43.0	43.0
	22	0.0	5.6	8.7	27.2	38.0	38.0	38.0	38.0
	23	0.0	4.2	6.7	23.5	33.2	33.2	33.2	33.2
	24	0.0	3.1	5.2	20.2	28.8	28.8	28.8	28.8
	25	0.0	2.2	3.9	17.1	24.6	24.6	24.6	24.6
	26	0.0	1.6	2.9	14.5	21.0	21.0	21.0	21.0
	27	0.0	1.1	2.2	12.1	17.6	17.6	17.6	17.6
	28	0.0	0.8	1.6	10.0	14.6	14.6	14.6	14.6
	29	0.0	0.5	1.1	8.2	12.1	12.1	12.1	12.1
	30	0.0	0.4	0.8	6.6	9.7	9.7	9.7	9.7
	31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-4-6: Survival Rates for Light Trucks (%)

		Vehicle Model *75 & before*	*1970*	*1980*	*1990*	*2000*	*2010*	*2020*	*2030*
Vehicle	**1**	45.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Age	**2**	41.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
(year)	**3**	36.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	4	32.1	99.7	99.1	99.3	99.5	99.5	99.5	99.5
	5	28.0	97.5	96.6	96.9	97.2	97.2	97.2	97.2
	6	24.2	94.9	93.7	94.1	94.5	94.5	94.5	94.5
	7	20.7	91.8	90.2	90.7	91.2	91.2	91.2	91.2
	8	17.5	88.3	86.3	86.9	87.5	87.5	87.5	87.5
	9	14.7	84.4	82.0	82.7	83.4	83.4	83.4	83.4
	10	12.2	80.2	77.3	78.2	79.1	79.1	79.1	79.1
	11	10.1	75.7	72.4	73.4	74.4	74.4	74.4	74.4
	12	8.2	70.9	67.3	68.4	69.5	69.5	69.5	69.5
	13	6.6	66.0	62.1	63.3	64.5	64.5	64.5	64.5
	14	5.2	61.0	56.8	58.0	59.2	59.2	59.2	59.2
	15	0.0	55.9	51.5	52.8	54.1	54.1	54.1	54.1
	16	0.0	50.8	46.3	47.7	49.1	49.1	49.1	49.1
	17	0.0	45.9	41.3	42.7	44.1	44.1	44.1	44.1
	18	0.0	41.1	36.5	37.9	39.3	39.3	39.3	39.3
	19	0.0	36.4	32.0	33.3	34.6	34.6	34.6	34.6
	20	0.0	32.1	27.7	29.0	30.3	30.3	30.3	30.3
	21	0.0	28.0	23.8	25.0	26.2	26.2	26.2	26.2
	22	0.0	24.2	20.3	21.4	22.5	22.5	22.5	22.5
	23	0.0	20.7	17.1	18.1	19.1	19.1	19.1	19.1
	24	0.0	17.5	14.2	15.2	16.2	16.2	16.2	16.2
	25	0.0	14.7	11.7	12.6	13.5	13.5	13.5	13.5
	26	0.0	12.2	9.6	10.3	11.0	11.0	11.0	11.0
	27	0.0	10.1	7.7	8.4	9.1	9.1	9.1	9.1
	28	0.0	8.2	6.2	6.7	7.2	7.2	7.2	7.2
	29	0.0	6.6	4.9	5.3	5.7	5.7	5.7	5.7
	30	0.0	5.2	3.8	4.2	4.6	4.6	4.6	4.6
	31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-4-7: Population Inventory for Two-seater Cars (units)

		Vehicle Model																
		75 & before	***1976***	***1977***	***1978***	***1979***	***1980***	**… …**	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***TOTAL***
Year	**1976**	2,072,075	199,716	0	0	0	0	**… …**	0	0	0	0	0	0	0	0	2,271,791
	1977	1,114,776	199,716	221,444	0	0	0	**… …**	0	0	0	0	0	0	0	0	1,535,936
	1978	971,803	199,716	221,444	214,146	0	0	**… …**	0	0	0	0	0	0	0	0	1,607,109
	1979	835,046	199,716	221,444	214,146	231,215	0	**… …**	0	0	0	0	0	0	0	0	1,701,567
	1980	708,650	197,719	221,444	214,146	231,215	215,964	**… …**	0	0	0	0	0	0	0	0	1,789,137
	1981	594,685	187,933	219,230	214,146	231,215	215,964	**… …**	0	0	0	0	0	0	0	0	1,906,134
	1982	491,082	176,549	208,379	212,005	231,215	215,964	**… …**	0	0	0	0	0	0	0	0	1,981,083
	1983	399,910	163,767	195,756	201,511	228,903	215,964	**… …**	0	0	0	0	0	0	0	0	2,055,144
	1984	321,172	150,186	181,584	189,305	217,573	215,964	**… …**	0	0	0	0	0	0	0	0	2,254,084
	1985	254,865	136,007	166,526	175,600	204,394	207,973	**… …**	0	0	0	0	0	0	0	0	2,497,362
	1986	198,919	121,627	150,803	161,038	189,596	197,175	**… …**	0	0	0	0	0	0	0	0	2,639,934
	1987	153,334	107,447	134,859	145,833	173,874	185,081	**… …**	0	0	0	0	0	0	0	0	2,747,399
	1988	116,036	93,667	119,137	130,415	157,457	172,123	**… …**	0	0	0	0	0	0	0	0	2,790,654
	1989	87,027	80,486	103,857	115,211	140,810	158,302	**… …**	0	0	0	0	0	0	0	0	2,798,109
	1990	64,234	68,303	89,242	100,434	124,394	143,832	**… …**	0	0	0	0	0	0	0	0	2,803,928
	1991	45,586	57,318	75,734	86,301	108,440	129,578	**… …**	0	0	0	0	0	0	0	0	2,762,479
	1992	33,153	47,333	63,554	73,238	93,180	115,109	**… …**	0	0	0	0	0	0	0	0	2,661,978
	1993	22,793	38,545	52,482	61,460	79,076	101,287	**… …**	0	0	0	0	0	0	0	0	2,541,022
	1994	16,577	30,956	42,739	50,753	66,359	88,113	**… …**	0	0	0	0	0	0	0	0	2,413,746
	1995	10,360	24,565	34,324	41,330	54,798	75,803	**… …**	0	0	0	0	0	0	0	0	2,273,392
	1996	8,288	19,173	27,238	33,193	44,624	64,357	**… …**	0	0	0	0	0	0	0	0	2,149,930
	1997	0	14,779	21,259	26,340	35,838	53,991	**… …**	0	0	0	0	0	0	0	0	2,040,896
	1998	0	11,184	16,387	20,558	28,439	44,921	**… …**	0	0	0	0	0	0	0	0	1,964,910
	1999	0	8,388	12,401	15,847	22,197	36,714	**… …**	0	0	0	0	0	0	0	0	1,898,086
	2000	0	6,191	9,301	11,992	17,110	29,803	**… …**	0	0	0	0	0	0	0	0	1,858,996
	2001	0	4,394	6,865	8,994	12,948	23,756	**… …**	0	0	0	0	0	0	0	0	1,824,736
	2002	0	3,195	4,872	6,639	9,711	18,789	**… …**	0	0	0	0	0	0	0	0	1,816,919
	2003	0	2,197	3,543	4,711	7,168	14,470	**… …**	0	0	0	0	0	0	0	0	1,849,623
	… …	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**
	2023	0	0	0	0	0	0	**… …**	76,587	0	0	0	0	0	0	0	2,303,549
	2024	0	0	0	0	0	0	**… …**	76,587	72,532	0	0	0	0	0	0	2,261,505
	2025	0	0	0	0	0	0	**… …**	76,587	72,532	68,526	0	0	0	0	0	2,213,344
	2026	0	0	0	0	0	0	**… …**	76,587	72,532	68,526	64,572	0	0	0	0	2,160,259
	2027	0	0	0	0	0	0	**… …**	76,587	72,532	68,526	64,572	60,671	0	0	0	2,101,485
	2028	0	0	0	0	0	0	**… …**	76,587	72,532	68,526	64,572	60,671	56,826	0	0	2,037,250
	2029	0	0	0	0	0	0	**… …**	76,587	72,532	68,526	64,572	60,671	56,826	53,039	0	1,968,477
	2030	0	0	0	0	0	0	**… …**	76,587	72,532	68,526	64,572	60,671	56,826	53,039	49,313	1,896,742

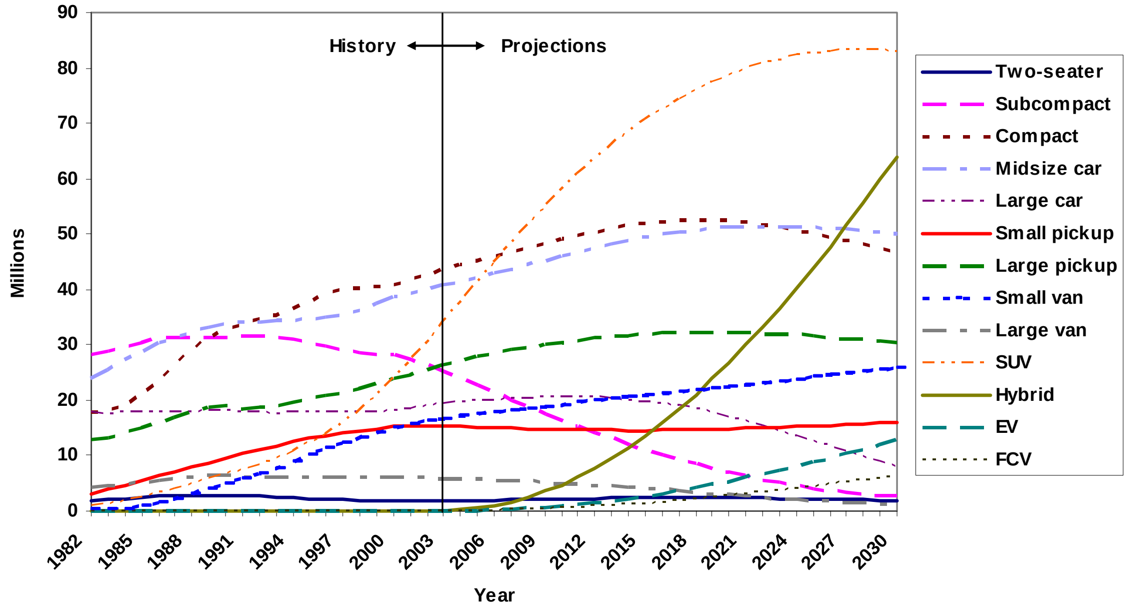

Figure A-4-1: The U.S. LDV Fleet Stock (Version 1)

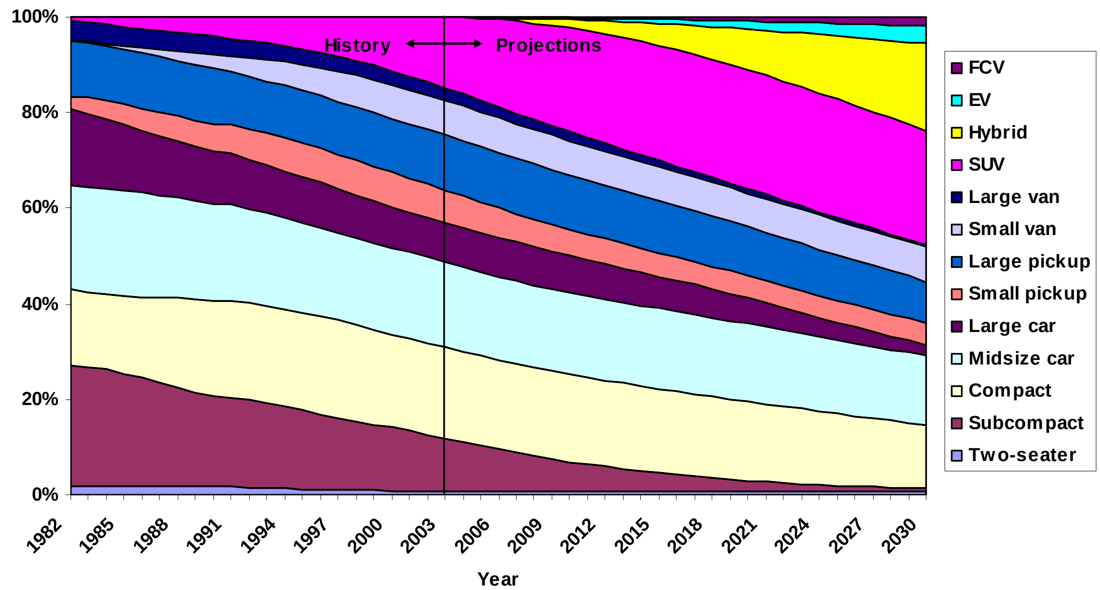

Figure A-4-2: Population Composition of the U.S. LDV Fleet (Version 1)

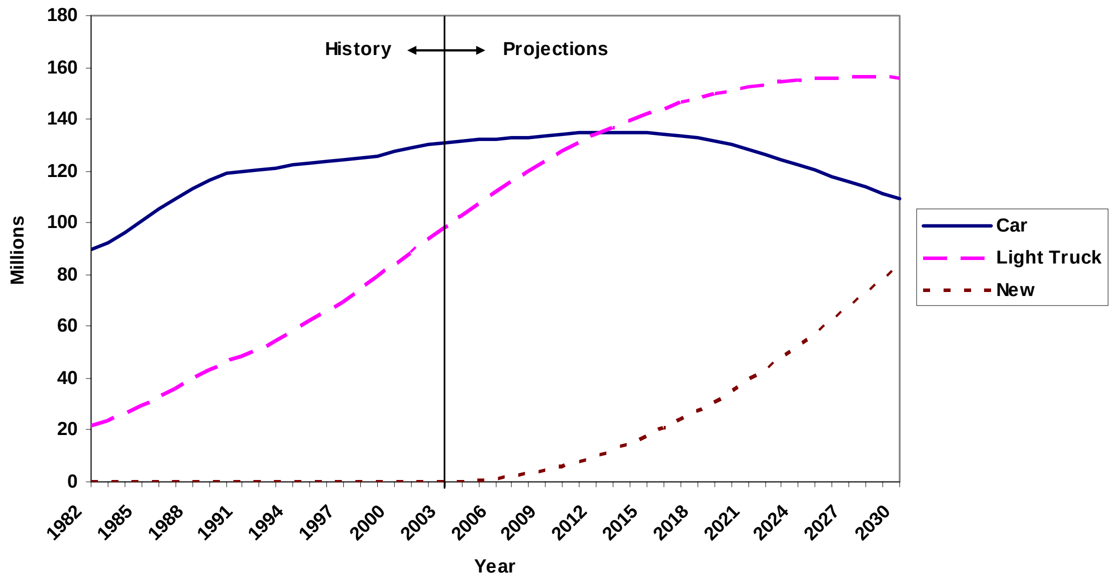

Figure A-4-3: The U.S. LDV Fleet Stock (Version 3)

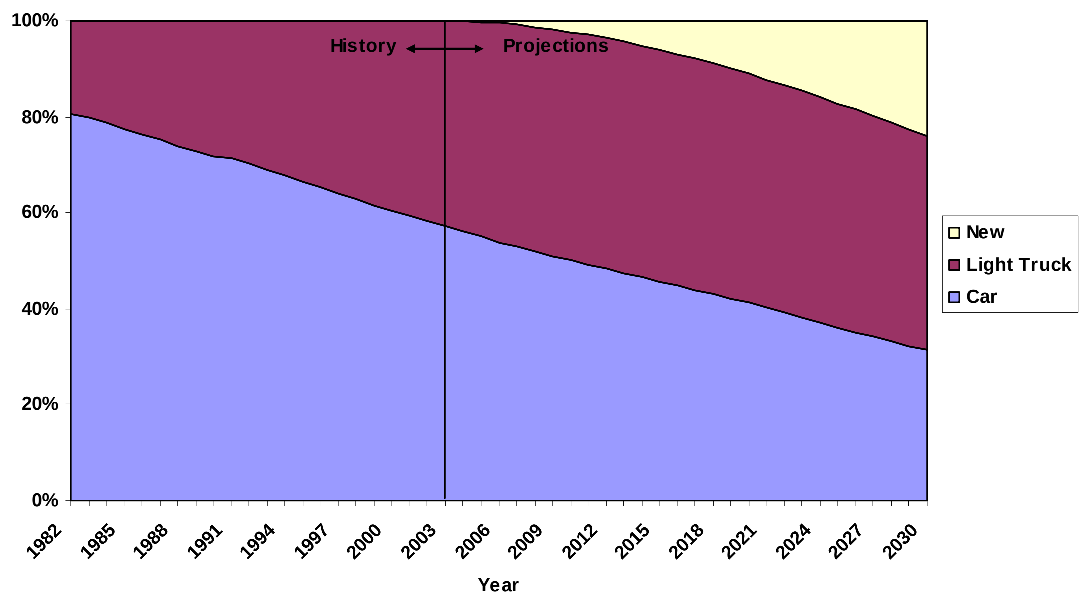

Figure A-4-4: Population Composition of the U.S. LDV Fleet (Version 3)

Table A-4-8: Vehicle Usage Inventory for Passenger Cars (miles / year / unit)

		Vehicle Model															
		75 & before	*1976*	*1977*	*1978*	*1979*	*1980*	*1981*	**… …**	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*
Year	**1982**	9,042	9,280	9,517	9,835	10,231	10,866	11,342	**… …**	0	0	0	0	0	0	0	0
	1983	8,912	9,153	9,393	9,634	9,955	10,357	10,999	**… …**	0	0	0	0	0	0	0	0
	1984	8,696	9,021	9,265	9,509	9,753	10,078	10,484	**… …**	0	0	0	0	0	0	0	0
	1985	8,145	8,803	9,132	9,379	9,625	9,872	10,201	**… …**	0	0	0	0	0	0	0	0
	1986	7,495	8,245	8,911	9,244	9,494	9,744	9,993	**… …**	0	0	0	0	0	0	0	0
	1987	7,924	7,587	8,346	9,020	9,357	9,610	9,863	**… …**	0	0	0	0	0	0	0	0
	1988	6,997	8,022	7,680	8,448	9,131	9,472	9,728	**… …**	0	0	0	0	0	0	0	0
	1989	7,083	7,083	8,120	7,774	8,552	9,243	9,588	**… …**	0	0	0	0	0	0	0	0
	1990	6,296	7,170	7,170	8,220	7,870	8,657	9,356	**… …**	0	0	0	0	0	0	0	0
	1991	4,691	6,373	7,258	7,258	8,321	7,966	8,763	**… …**	0	0	0	0	0	0	0	0
	1992	4,749	4,749	6,451	7,347	7,347	8,423	8,064	**… …**	0	0	0	0	0	0	0	0
	1993	4,807	4,807	4,807	6,531	7,438	7,438	8,526	**… …**	0	0	0	0	0	0	0	0
	1994	4,866	4,866	4,866	4,866	6,611	7,529	7,529	**… …**	0	0	0	0	0	0	0	0
	1995	4,926	4,926	4,926	4,926	4,926	6,692	7,621	**… …**	0	0	0	0	0	0	0	0
	1996	4,986	4,986	4,986	4,986	4,986	4,986	6,774	**… …**	0	0	0	0	0	0	0	0
	1997	0	5,048	5,048	5,048	5,048	5,048	5,048	**… …**	0	0	0	0	0	0	0	0
	1998	0	5,110	5,110	5,110	5,110	5,110	5,110	**… …**	0	0	0	0	0	0	0	0
	1999	0	5,172	5,172	5,172	5,172	5,172	5,172	**… …**	0	0	0	0	0	0	0	0
	2000	0	5,236	5,236	5,236	5,236	5,236	5,236	**… …**	0	0	0	0	0	0	0	0
	2001	0	5,300	5,300	5,300	5,300	5,300	5,300	**… …**	0	0	0	0	0	0	0	0
	2002	0	5,365	5,365	5,365	5,365	5,365	5,365	**… …**	0	0	0	0	0	0	0	0
	2003	0	5,431	5,431	5,431	5,431	5,431	5,431	**… …**	0	0	0	0	0	0	0	0
	2004	0	5,498	5,498	5,498	5,498	5,498	5,498	**… …**	0	0	0	0	0	0	0	0
	2005	0	5,565	5,565	5,565	5,565	5,565	5,565	**… …**	0	0	0	0	0	0	0	0
	2006	0	5,633	5,633	5,633	5,633	5,633	5,633	**… …**	0	0	0	0	0	0	0	0
	2007	0	0	5,702	5,702	5,702	5,702	5,702	**… …**	0	0	0	0	0	0	0	0
	2008	0	0	0	5,772	5,772	5,772	5,772	**… …**	0	0	0	0	0	0	0	0
	2009	0	0	0	0	5,843	5,843	5,843	**… …**	0	0	0	0	0	0	0	0
	… …	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**
	2023	0	0	0	0	0	0	0	**… …**	19,617	0	0	0	0	0	0	0
	2024	0	0	0	0	0	0	0	**… …**	18,932	19,858	0	0	0	0	0	0
	2025	0	0	0	0	0	0	0	**… …**	18,360	19,164	20,102	0	0	0	0	0
	2026	0	0	0	0	0	0	0	**… …**	17,500	18,585	19,399	20,349	0	0	0	0
	2027	0	0	0	0	0	0	0	**… …**	17,028	17,715	18,813	19,637	20,598	0	0	0
	2028	0	0	0	0	0	0	0	**… …**	16,681	17,237	17,932	19,044	19,878	20,851	0	0
	2029	0	0	0	0	0	0	0	**… …**	16,464	16,886	17,449	18,152	19,278	20,122	21,107	0
	2030	0	0	0	0	0	0	0	**… …**	16,238	16,666	17,093	17,663	18,375	19,515	20,369	21,366

Table A-4-9: Vehicle Usage Inventory for Light Trucks (miles / year / unit)

		Vehicle Model 75 & before	1976	1977	1978	1979	1980	1981	……	2023	2024	2025	2026	2027	2028	2029	2030
Year	1982	13,973	14,154	15,424	15,878	16,241	17,965	17,420	……	0	0	0	0	0	0	0	0
	1983	13,771	14,044	14,227	15,503	15,959	16,324	18,057	……	0	0	0	0	0	0	0	0
	1984	12,100	13,841	14,116	14,300	15,583	16,041	16,408	……	0	0	0	0	0	0	0	0
	1985	8,476	12,162	13,912	14,189	14,373	15,663	16,124	……	0	0	0	0	0	0	0	0
	1986	8,520	8,520	12,224	13,984	14,262	14,447	15,743	……	0	0	0	0	0	0	0	0
	1987	8,564	8,564	8,564	12,287	14,056	14,335	14,521	……	0	0	0	0	0	0	0	0
	1988	8,608	8,608	8,608	8,608	12,350	14,128	14,408	……	0	0	0	0	0	0	0	0
	1989	8,652	8,652	8,652	8,652	8,652	12,413	14,200	……	0	0	0	0	0	0	0	0
	1990	8,696	8,696	8,696	8,696	8,696	8,696	12,477	……	0	0	0	0	0	0	0	0
	1991	8,741	8,741	8,741	8,741	8,741	8,741	8,741	……	0	0	0	0	0	0	0	0
	1992	8,786	8,786	8,786	8,786	8,786	8,786	8,786	……	0	0	0	0	0	0	0	0
	1993	8,831	8,831	8,831	8,831	8,831	8,831	8,831	……	0	0	0	0	0	0	0	0
	1994	8,876	8,876	8,876	8,876	8,876	8,876	8,876	……	0	0	0	0	0	0	0	0
	1995	8,922	8,922	8,922	8,922	8,922	8,922	8,922	……	0	0	0	0	0	0	0	0
	1996	8,967	8,967	8,967	8,967	8,967	8,967	8,967	……	0	0	0	0	0	0	0	0
	1997	0	9,014	9,014	9,014	9,014	9,014	9,014	……	0	0	0	0	0	0	0	0
	1998	0	9,060	9,060	9,060	9,060	9,060	9,060	……	0	0	0	0	0	0	0	0
	1999	0	9,106	9,106	9,106	9,106	9,106	9,106	……	0	0	0	0	0	0	0	0
	2000	0	9,153	9,153	9,153	9,153	9,153	9,153	……	0	0	0	0	0	0	0	0
	2001	0	9,200	9,200	9,200	9,200	9,200	9,200	……	0	0	0	0	0	0	0	0
	2002	0	9,247	9,247	9,247	9,247	9,247	9,247	……	0	0	0	0	0	0	0	0
	2003	0	9,295	9,295	9,295	9,295	9,295	9,295	……	0	0	0	0	0	0	0	0
	2004	0	9,342	9,342	9,342	9,342	9,342	9,342	……	0	0	0	0	0	0	0	0
	2005	0	9,390	9,390	9,390	9,390	9,390	9,390	……	0	0	0	0	0	0	0	0
	2006	0	9,439	9,439	9,439	9,439	9,439	9,439	……	0	0	0	0	0	0	0	0
	2007	0	0	9,487	9,487	9,487	9,487	9,487	……	0	0	0	0	0	0	0	0
	2008	0	0	0	9,536	9,536	9,536	9,536	……	0	0	0	0	0	0	0	0
	2009	0	0	0	0	9,585	9,585	9,585	……	0	0	0	0	0	0	0	0
	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……
	2023	0	0	0	0	0	0	0	……	19,586	0	0	0	0	0	0	0
	2024	0	0	0	0	0	0	0	……	21,599	19,687	0	0	0	0	0	0
	2025	0	0	0	0	0	0	0	……	22,389	21,710	19,788	0	0	0	0	0
	2026	0	0	0	0	0	0	0	……	20,344	22,503	21,821	19,889	0	0	0	0
	2027	0	0	0	0	0	0	0	……	19,991	20,448	22,619	21,933	19,991	0	0	0
	2028	0	0	0	0	0	0	0	……	19,520	20,094	20,553	22,735	22,046	20,094	0	0
	2029	0	0	0	0	0	0	0	……	18,004	19,620	20,197	20,659	22,852	22,159	20,197	0
	2030	0	0	0	0	0	0	0	……	17,865	18,097	19,721	20,301	20,765	22,969	22,273	20,301

Table A-4-10: Real Characteristics Inventory for Fuel Consumption of Two-seater Cars (g / mile)

		Vehicle Model															
		75 & before	***1976***	***1977***	***1978***	***1979***	***1980***	***1981***	**… …**	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***
Year	**1982**	103.402	102.888	102.376	101.866	101.360	100.855	100.354	**… …**	0	0	0	0	0	0	0	0
	1983	103.919	103.402	102.888	102.376	101.866	101.360	100.855	**… …**	0	0	0	0	0	0	0	0
	1984	104.439	103.919	103.402	102.888	102.376	101.866	101.360	**… …**	0	0	0	0	0	0	0	0
	1985	104.961	104.439	103.919	103.402	102.888	102.376	101.866	**… …**	0	0	0	0	0	0	0	0
	1986	105.486	104.961	104.439	103.919	103.402	102.888	102.376	**… …**	0	0	0	0	0	0	0	0
	1987	106.013	105.486	104.961	104.439	103.919	103.402	102.888	**… …**	0	0	0	0	0	0	0	0
	1988	106.543	106.013	105.486	104.961	104.439	103.919	103.402	**… …**	0	0	0	0	0	0	0	0
	1989	107.076	106.543	106.013	105.486	104.961	104.439	103.919	**… …**	0	0	0	0	0	0	0	0
	1990	107.611	107.076	106.543	106.013	105.486	104.961	104.439	**… …**	0	0	0	0	0	0	0	0
	1991	108.149	107.611	107.076	106.543	106.013	105.486	104.961	**… …**	0	0	0	0	0	0	0	0
	1992	108.690	108.149	107.611	107.076	106.543	106.013	105.486	**… …**	0	0	0	0	0	0	0	0
	1993	109.233	108.690	108.149	107.611	107.076	106.543	106.013	**… …**	0	0	0	0	0	0	0	0
	1994	109.780	109.233	108.690	108.149	107.611	107.076	106.543	**… …**	0	0	0	0	0	0	0	0
	1995	110.328	109.780	109.233	108.690	108.149	107.611	107.076	**… …**	0	0	0	0	0	0	0	0
	1996	110.880	110.328	109.780	109.233	108.690	108.149	107.611	**… …**	0	0	0	0	0	0	0	0
	1997	111.435	110.880	110.328	109.780	109.233	108.690	108.149	**… …**	0	0	0	0	0	0	0	0
	1998	111.992	111.435	110.880	110.328	109.780	109.233	108.690	**… …**	0	0	0	0	0	0	0	0
	1999	112.552	111.992	111.435	110.880	110.328	109.780	109.233	**… …**	0	0	0	0	0	0	0	0
	2000	113.114	112.552	111.992	111.435	110.880	110.328	109.780	**… …**	0	0	0	0	0	0	0	0
	2001	113.680	113.114	112.552	111.992	111.435	110.880	110.328	**… …**	0	0	0	0	0	0	0	0
	2002	114.248	113.680	113.114	112.552	111.992	111.435	110.880	**… …**	0	0	0	0	0	0	0	0
	2003	114.820	114.248	113.680	113.114	112.552	111.992	111.435	**… …**	0	0	0	0	0	0	0	0
	2004	115.394	114.820	114.248	113.680	113.114	112.552	111.992	**… …**	0	0	0	0	0	0	0	0
	2005		115.394	114.820	114.248	113.680	113.114	112.552	**… …**	0	0	0	0	0	0	0	0
	2006			115.394	114.820	114.248	113.680	113.114	**… …**	0	0	0	0	0	0	0	0
	2007				115.394	114.820	114.248	113.680	**… …**	0	0	0	0	0	0	0	0
	2008					115.394	114.820	114.248	**… …**	0	0	0	0	0	0	0	0
	2009						115.394	114.820	**… …**	0	0	0	0	0	0	0	0
	… …	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**	**… …**
	2023	0	0	0	0	0	0	0	**… …**	103.663							
	2024	0	0	0	0	0	0	0	**… …**	104.181	103.642						
	2025	0	0	0	0	0	0	0	**… …**	104.702	104.160	103.616					
	2026	0	0	0	0	0	0	0	**… …**	105.226	104.681	104.134	103.587				
	2027	0	0	0	0	0	0	0	**… …**	105.752	105.204	104.655	104.104	103.553			
	2028	0	0	0	0	0	0	0	**… …**	106.281	105.730	105.178	104.625	104.070	103.515		
	2029	0	0	0	0	0	0	0	**… …**	106.812	106.259	105.704	105.148	104.591	104.032	103.472	
	2030	0	0	0	0	0	0	0	**… …**	107.346	106.790	106.233	105.674	105.114	104.552	103.990	103.426

Table A-4-11: Fuel Consumption of Two-seater Cars (million gallons / year)

		Vehicle Model 75 & before	1976	1977	1978	1979	1980	1981	... ...	2023	2024	2025	2026	2027	2028	2029	2030
Year	1982	163	60	72	76	85	84	98	... ...	0	0	0	0	0	0	0	0
	1983	132	55	67	71	83	81	96	... ...	0	0	0	0	0	0	0	0
	1984	104	50	62	66	77	79	92	... ...	0	0	0	0	0	0	0	0
	1985	78	45	56	61	72	75	90	... ...	0	0	0	0	0	0	0	0
	1986	56	37	50	55	66	70	85	... ...	0	0	0	0	0	0	0	0
	1987	46	31	42	49	60	65	80	... ...	0	0	0	0	0	0	0	0
	1988	31	28	34	41	53	60	75	... ...	0	0	0	0	0	0	0	0
	1989	24	22	32	34	45	54	69	... ...	0	0	0	0	0	0	0	0
	1990	15	19	24	31	37	47	62	... ...	0	0	0	0	0	0	0	0
	1991	8	14	21	24	34	39	53	... ...	0	0	0	0	0	0	0	0
	1992	6	9	16	21	26	37	44	... ...	0	0	0	0	0	0	0	0
	1993	4	7	10	15	22	29	42	... ...	0	0	0	0	0	0	0	0
	1994	3	6	8	10	17	25	33	... ...	0	0	0	0	0	0	0	0
	1995	2	5	7	8	10	19	29	... ...	0	0	0	0	0	0	0	0
	1996	2	4	5	6	9	12	22	... ...	0	0	0	0	0	0	0	0
	1997	0	3	4	5	7	11	14	... ...	0	0	0	0	0	0	0	0
	1998	0	2	3	4	6	9	12	... ...	0	0	0	0	0	0	0	0
	1999	0	2	3	3	5	7	10	... ...	0	0	0	0	0	0	0	0
	2000	0	1	2	2	4	6	8	... ...	0	0	0	0	0	0	0	0
	2001	0	1	1	2	3	5	7	... ...	0	0	0	0	0	0	0	0
	2002	0	1	1	1	2	4	6	... ...	0	0	0	0	0	0	0	0
	2003	0	0	1	1	2	3	5	... ...	0	0	0	0	0	0	0	0
	2004	0	0	1	1	1	2	4	... ...	0	0	0	0	0	0	0	0
	2005	0	0	0	1	1	2	3	... ...	0	0	0	0	0	0	0	0
	2006	0	0	0	0	1	1	2	... ...	0	0	0	0	0	0	0	0
	2007	0	0	0	0	0	1	2	... ...	0	0	0	0	0	0	0	0
	2008	0	0	0	0	0	1	1	... ...	0	0	0	0	0	0	0	0
	2009	0	0	0	0	0	1	1	... ...	0	0	0	0	0	0	0	0
	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...
	2023	0	0	0	0	0	0	0	... ...	55	0	0	0	0	0	0	0
	2024	0	0	0	0	0	0	0	... ...	54	53	0	0	0	0	0	0
	2025	0	0	0	0	0	0	0	... ...	52	52	51	0	0	0	0	0
	2026	0	0	0	0	0	0	0	... ...	50	50	49	48	0	0	0	0
	2027	0	0	0	0	0	0	0	... ...	49	48	48	47	46	0	0	0
	2028	0	0	0	0	0	0	0	... ...	48	47	46	46	45	44	0	0
	2029	0	0	0	0	0	0	0	... ...	48	46	45	44	44	42	41	0
	2030	0	0	0	0	0	0	0	... ...	48	46	44	43	42	41	40	39

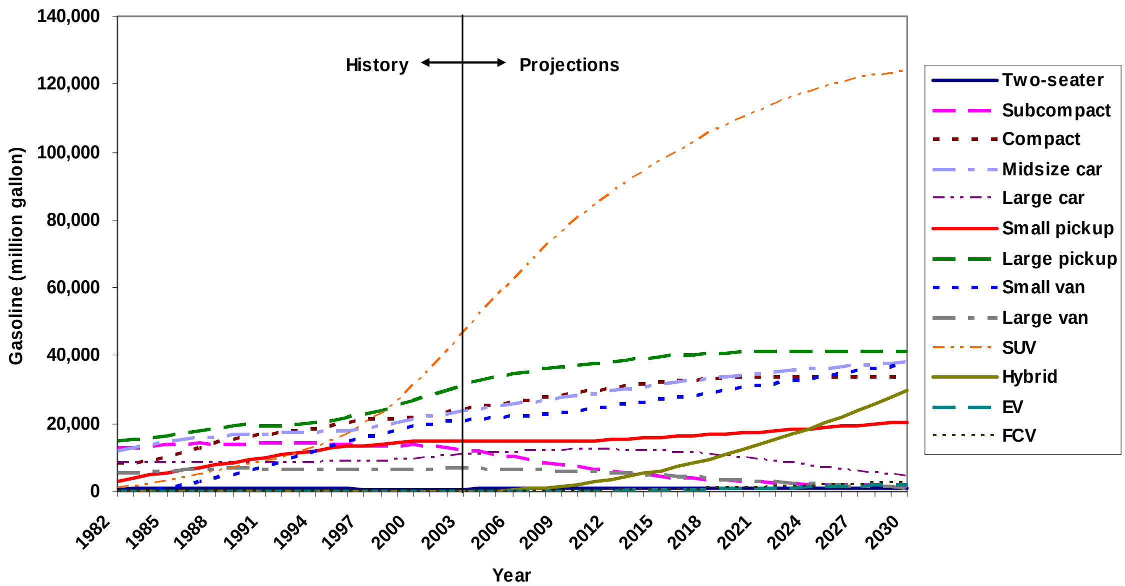

Figure A-4-5: Fuel Consumption of the U.S. LDV Fleet (Version 1)

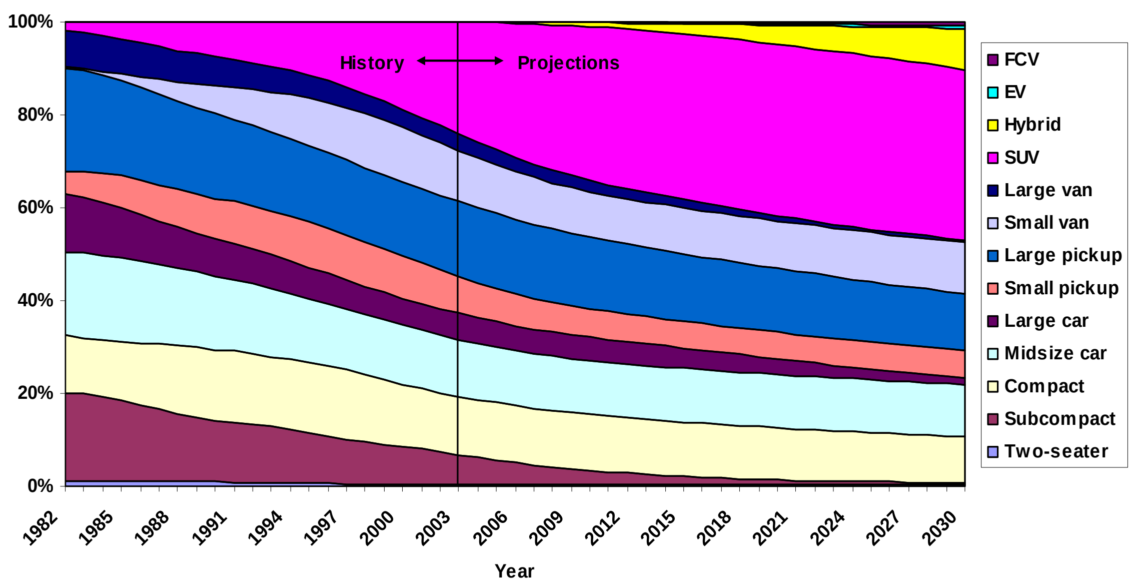

Figure A-4-6: Percentage Composition of the U.S. LDV Fleet Fuel Consumption (Version 1)

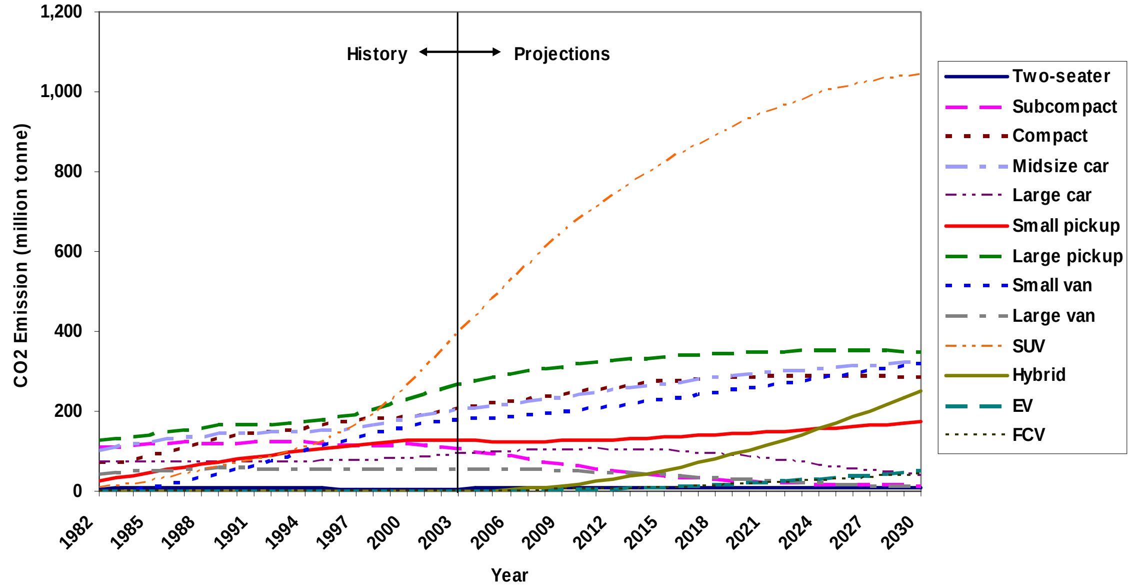

Figure A-4-7: CO_2 Emission of the U.S. LDV Fleet (Version 1)

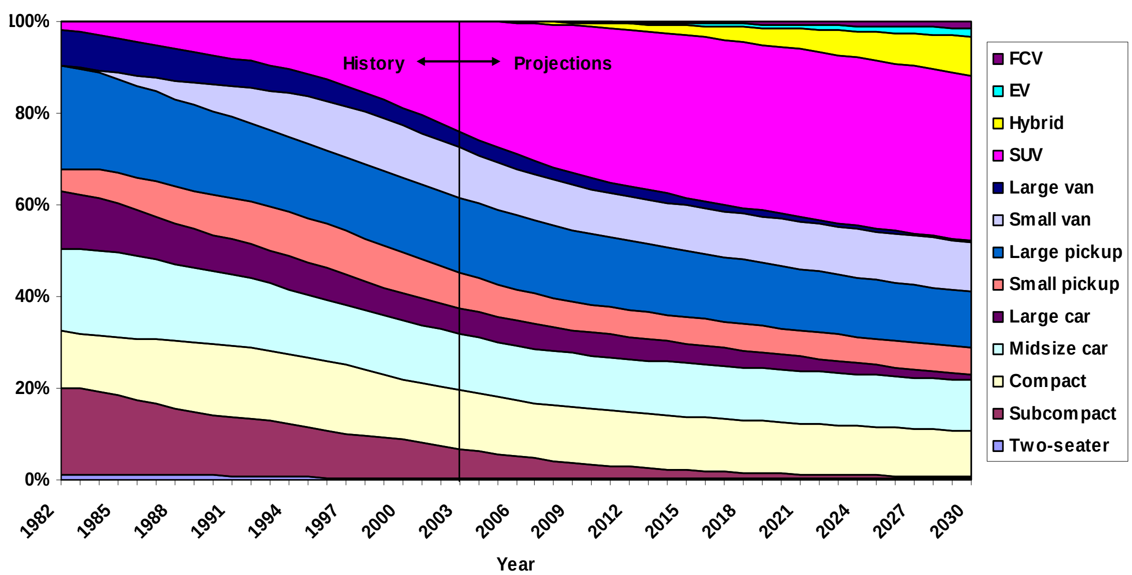

Figure A-4-8: Percentage Composition of the U.S. LDV Fleet CO_2 Emission (Version 1)

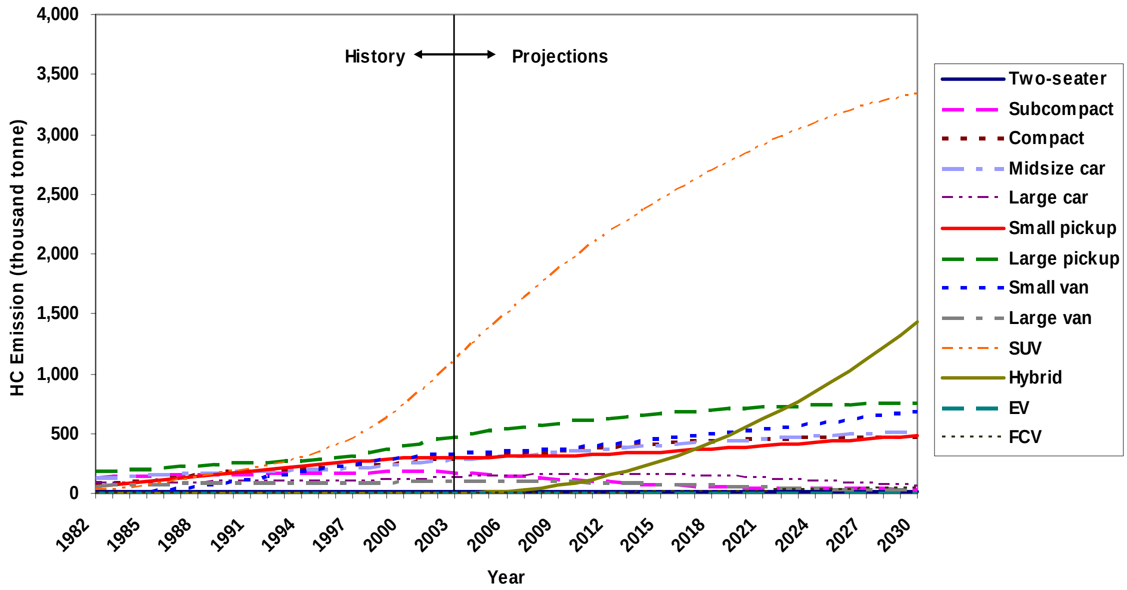

Figure A-4-9: HC Emission of the U.S. LDV Fleet (Version 1)

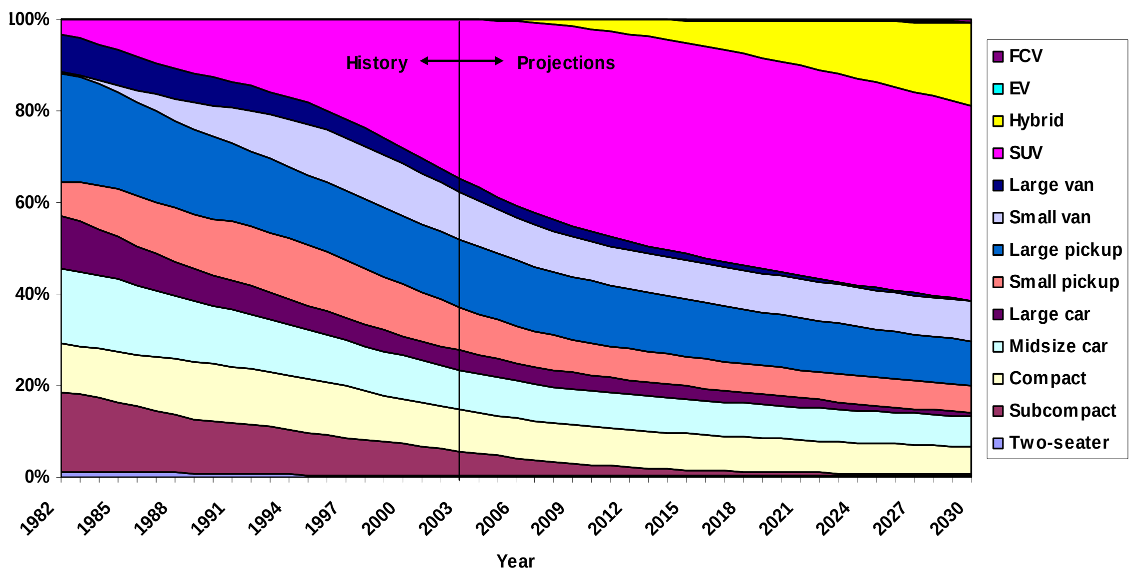

Figure A-4-10: Percentage Composition of the U.S. LDV Fleet HC Emission (Version 1)

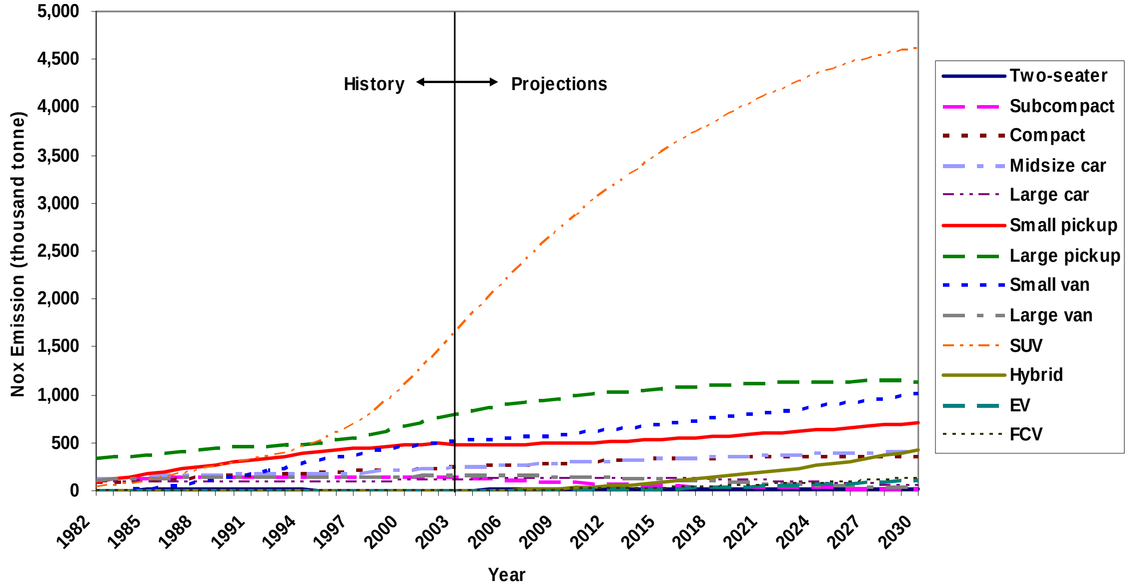

Figure A-4-11: NO_X Emission of the U.S. LDV Fleet (Version 1)

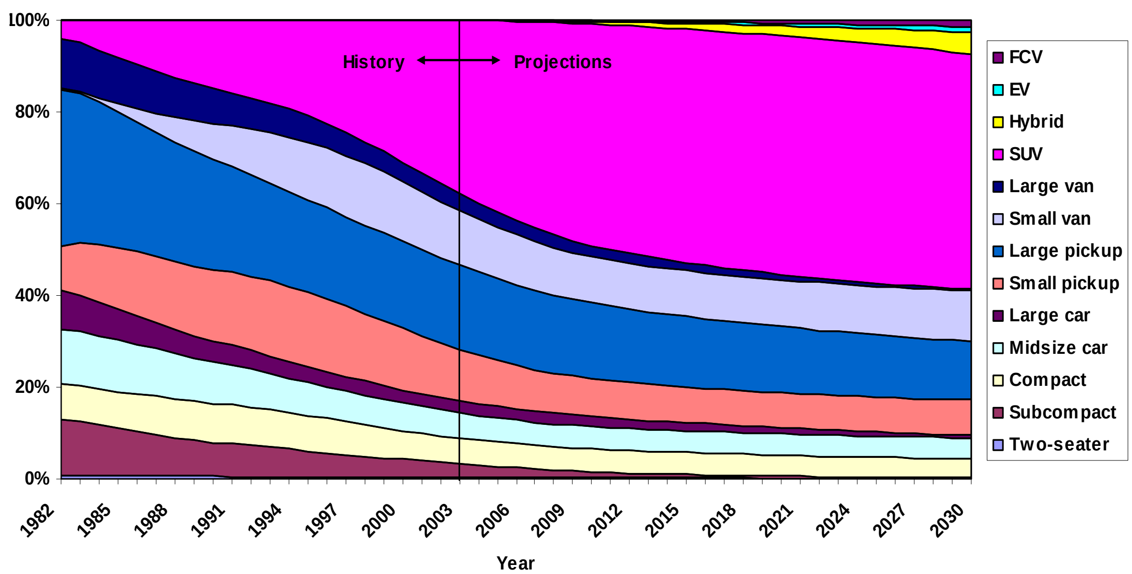

Figure A-4-12: Percentage Composition of the U.S. LDV Fleet NO_X Emission (Version 1)

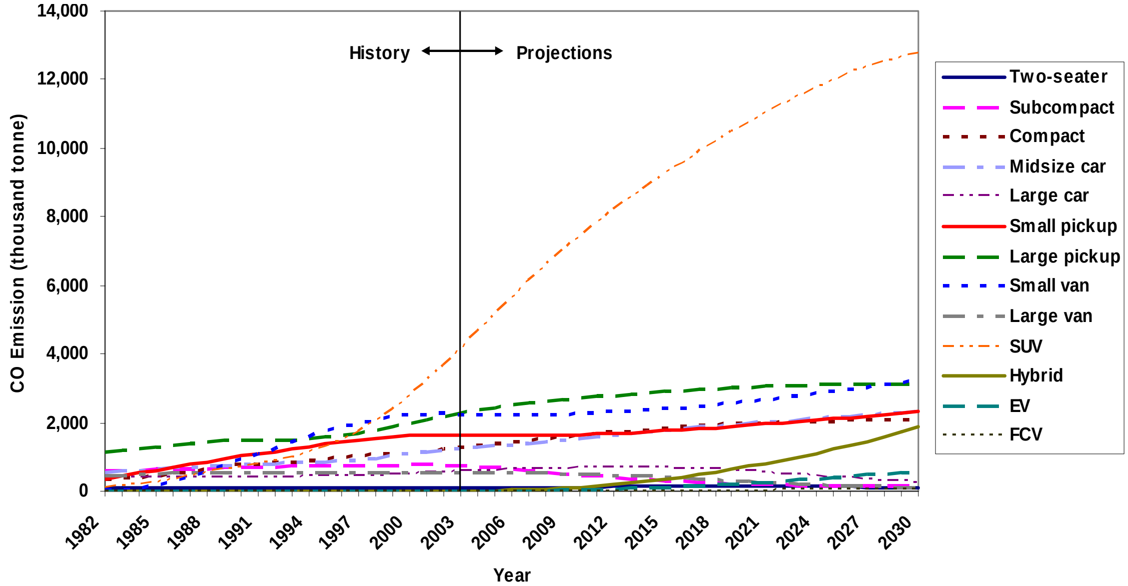

Figure A-4-13: CO Emission of the U.S. LDV Fleet (Version 1)

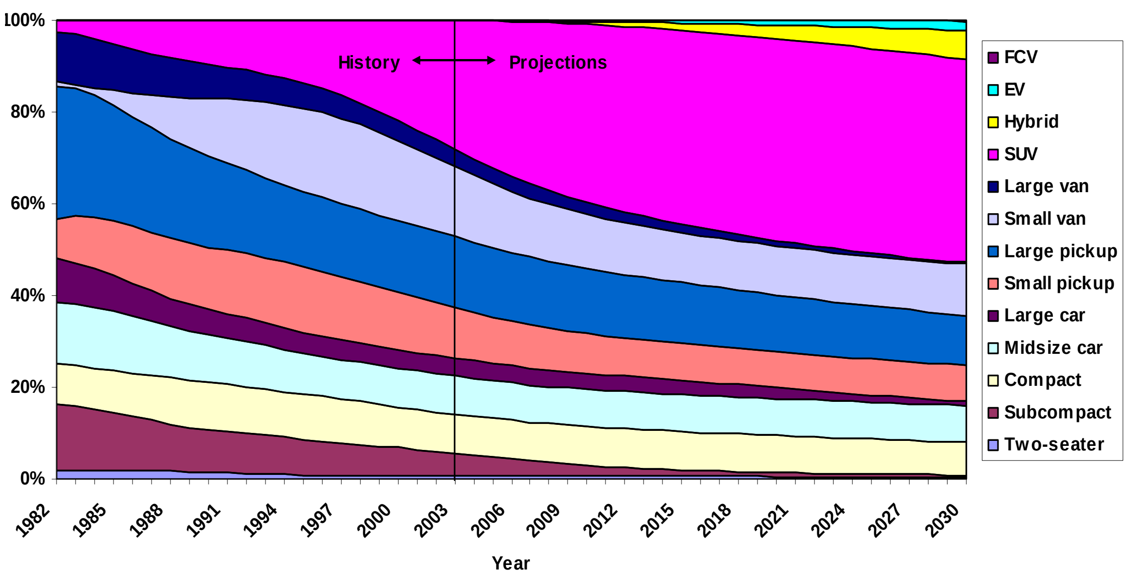

Figure A-4-14: Percentage Composition of the U.S. LDV Fleet CO Emission (Version 1)

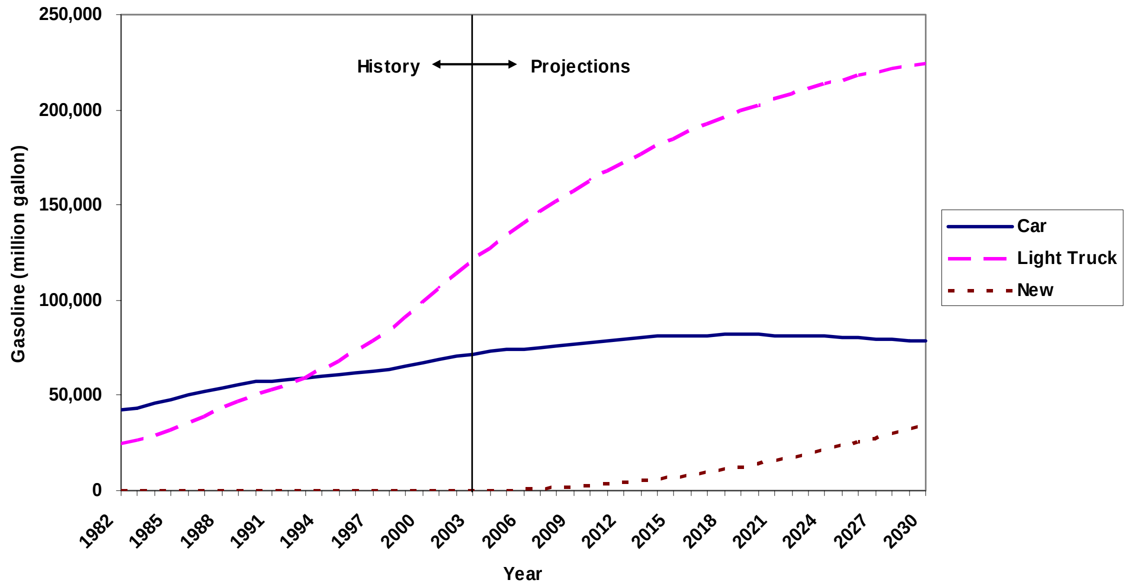

Figure A-4-15: Fuel Consumption of the U.S. LDV Fleet (Version 3)

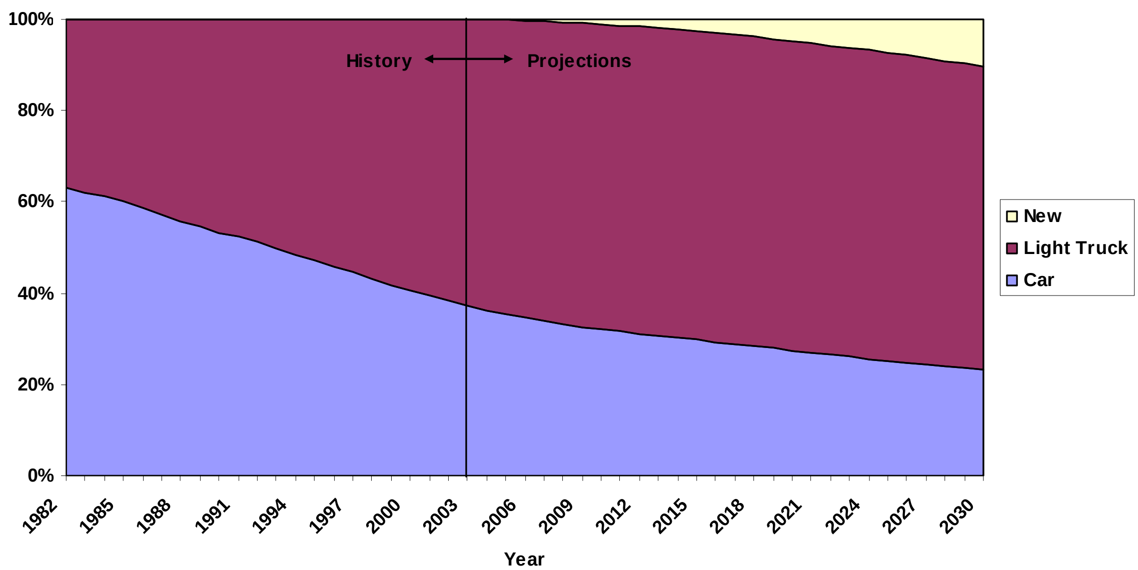

Figure A-4-16: Percentage Composition of the U.S. LDV Fleet Fuel Consumption (Version 3)

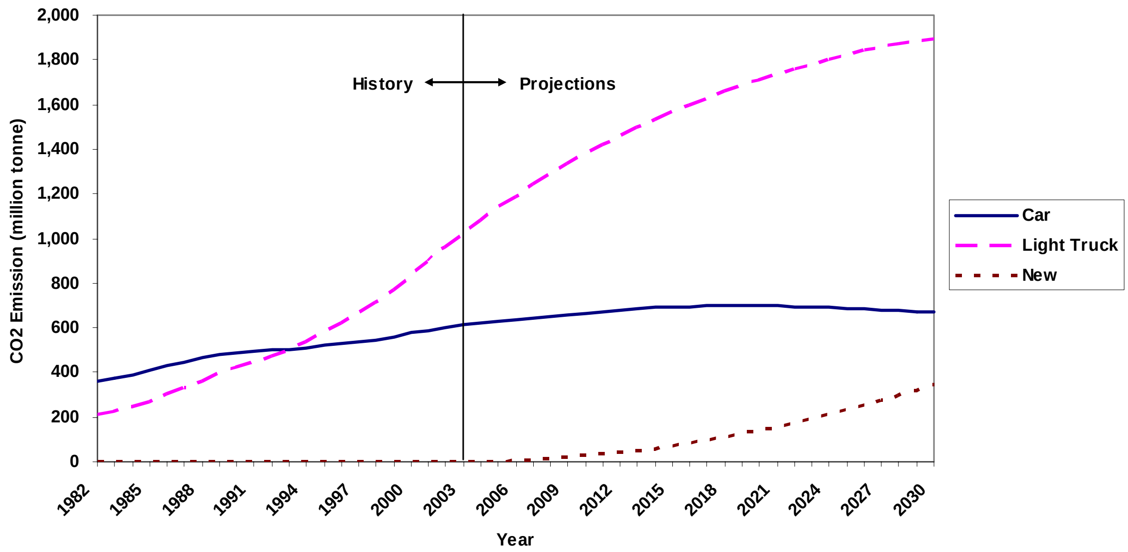

Figure A-4-17: CO_2 Emission of the U.S. LDV Fleet (Version 3)

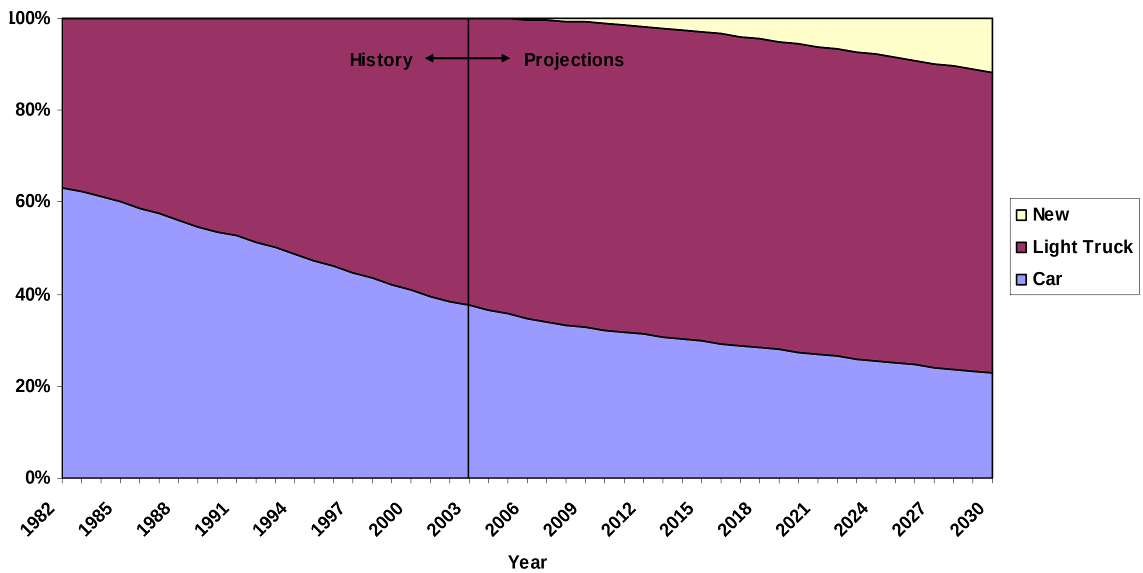

Figure A-4-18: Percentage Composition of the U.S. LDV Fleet CO_2 Emission (Version 3)

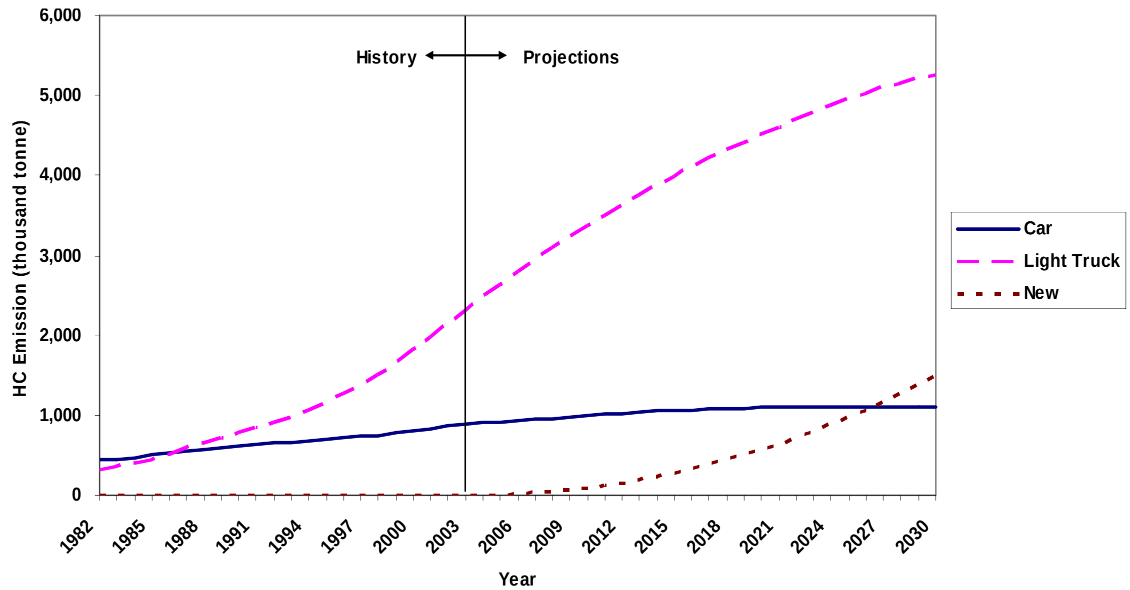

Figure A-4-19: HC Emission of the U.S. LDV Fleet (Version 3)

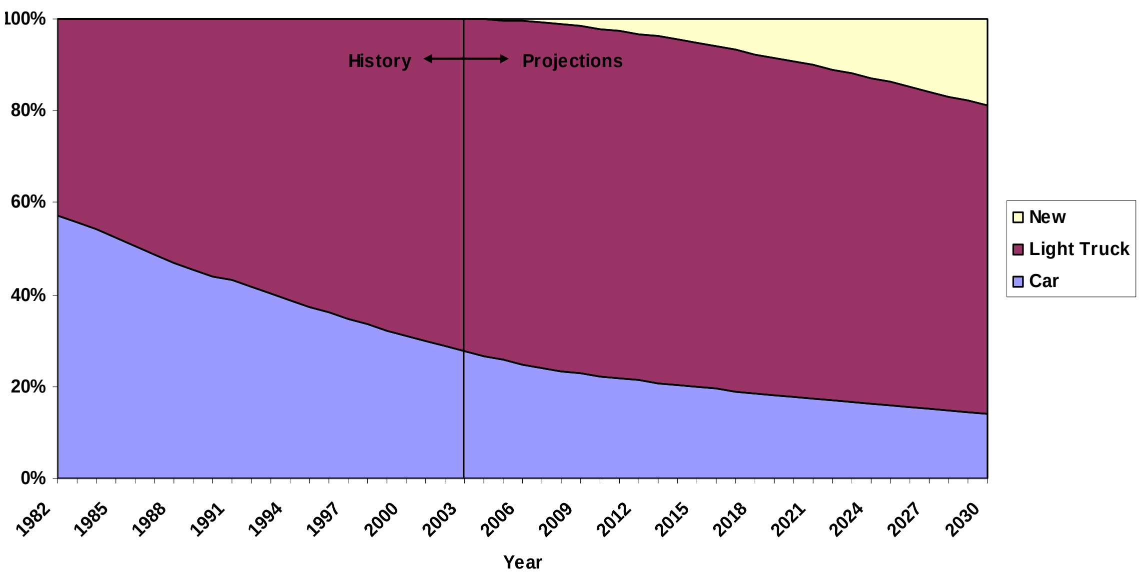

Figure A-4-20: Percentage Composition of the U.S. LDV Fleet HC Emission (Version 3)

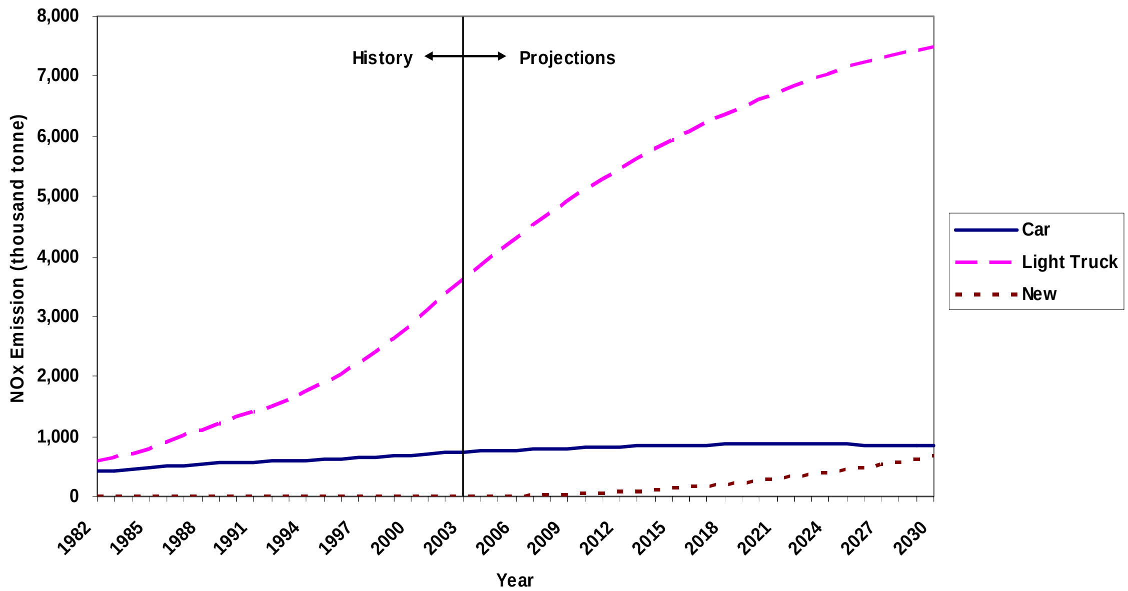

Figure A-4-21: NO_X Emission of the U.S. LDV Fleet (Version 3)

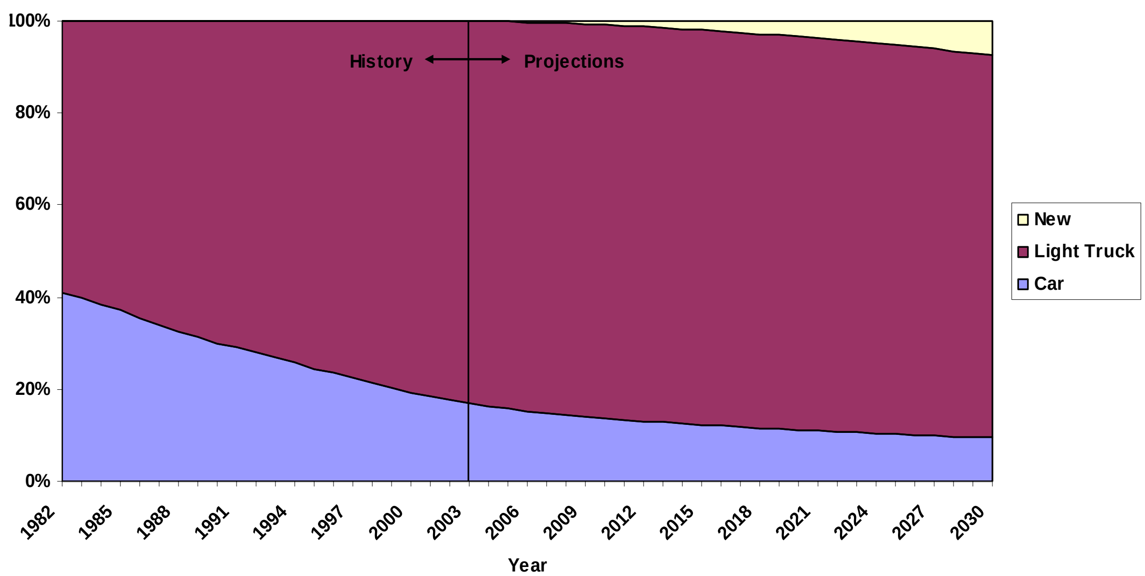

Figure A-4-22: Percentage Composition of the U.S. LDV Fleet NO_X Emission (Version 3)

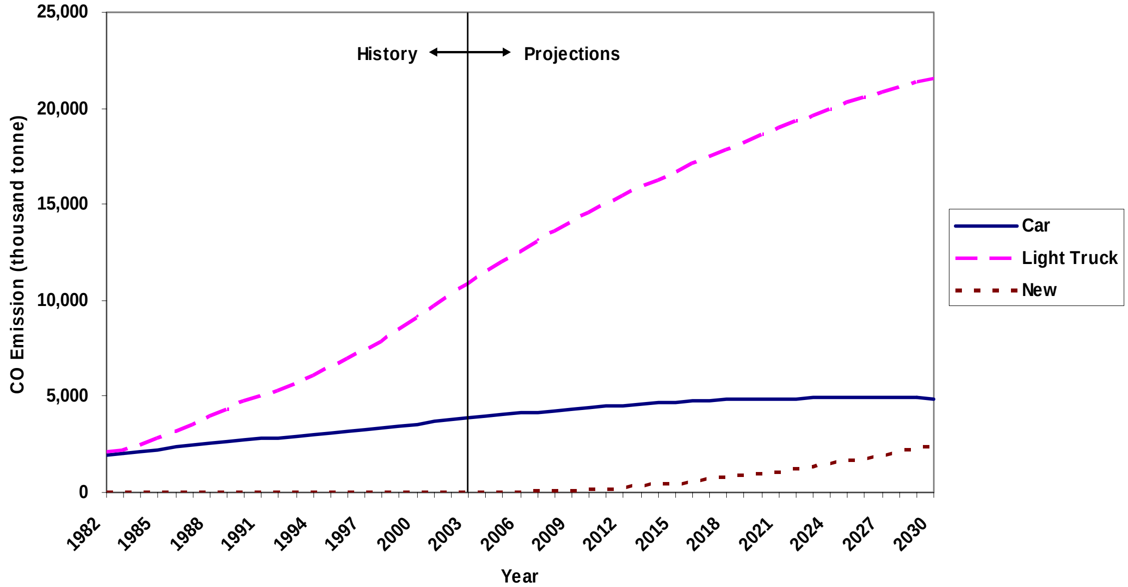

Figure A-4-23: CO Emission of the U.S. LDV Fleet (Version 3)

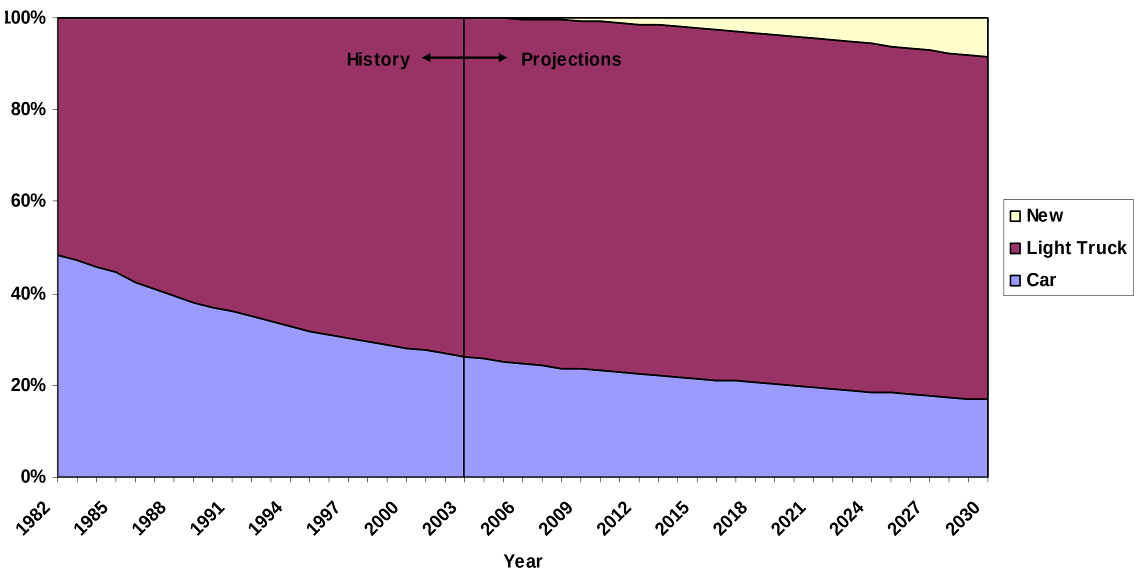

Figure A-4-24: Percentage Composition of the U.S. LDV Fleet CO Emission (Version 3)