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DRAFT FOR REVIEW

Effect of Speeds and Speed Limit Enforcement on Potential Emissions Reduction and Safety

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) designates the areas that do not meet the National Ambient Air Quality Standards (NAAQS) as nonattainment areas. These areas must submit air quality plans, known as State Implementation Plans (SIPs), showing how they will attain the standards. If they fail to do this, they face sanctions and other penalties, such as the possible loss of highway funds, under the Clean Air Act Amendments of 1990 (CAAA). Many of these nonattainment areas have used, or attempted to use, various strategies in their SIPs to reduce emissions. These strategies include vehicle inspection and maintenance (I/M) programs, transportation control measures (TCM), clean fuel programs, etc.

It is well known that a vehicle operating at higher speeds on a highway will generally emit higher amounts of pollutants as the engine will work at higher loads and consume more fuel; therefore, strategies targeted at lowering the average non-congested traffic flow speed would have large potential air quality benefits. The purpose of this task was to investigate the potential benefits of speed limit enforcement on vehicle emissions and safety on high-speed roads. Speeding vehicles produce increased emissions and can increase the severity of injuries when crashes occur. This task identified the effect of speed limit enforcement, which, if implemented, has the potential to improve air quality and safety. Additionally, a field study was conducted in a Texas near-nonattainment area (Travis County), to identify the potential impacts of speed limit enforcement on a regional basis.

LITERATURE REVIEW

The current literature on speed limit reduction and its effect on safety and emissions were reviewed. The research team focused primarily on analyses conducted in the past five years. The demise of environmental speed limits in the U.S. has created a scarcity of research on the relationship between speed limit reduction and enforcement programs and emissions reduction. Research on safety increases and speed reductions is however more readily available.

Safety and Speed Reduction

The works cited in the following are those that focused on establishing a mathematical relationship between a percentage in speed reduction and the resulting percentage decrease in crashes.

In an effort to reduce fuel consumption, the U.S. Congress in 1974 imposed a nationwide 55 mph speed limit, and some European countries followed suit. In the U.S., the 55-mph limit resulted in a reduction in highway fatalities of more than 9,000 in the first year and between 3,000-5,000 fatalities annually thereafter. By the mid-1980s, there continued to be between 2,000-4,000 fewer fatalities and between 2,500-4,500 fewer serious, severe, and critical injuries from crashes compared with pre-1974 roadway deaths. Lower speeds were credited with most of the decline. (Richter et al. 2006)

Richter et al. (2006) also reported that reduced speed limits, speed-camera networks, and speed calming substantially reduce roadway deaths in absolute numbers. This trend is apparent in the United Kingdom, Australia, France, and other countries, but not in the U.S., which has raised speed limits in the past two decades and does not use extensive speed-camera networks.

Richter et al. (2006) additionally noted that crash and death rates per vehicle miles traveled (VMT) are much lower on high-speed roads compared with other roads, including urban roads, because of superior design standards. Researchers noted that as speeds increase or decrease, the effect of a given reduction in speed has been found to be greater on lower-speed than on high-speed roads, although some U.S. studies suggest otherwise.

In another recent study by Hirst et al. (2005), a series of mathematical models were developed to predict the impact of speed management programs on crashes and its variability both with changes in speed and with site and program characteristics. It was found that the impact of schemes with vertical deflections (speed humps, cushions) is independent of the change in mean speed: a crash reduction of 44% is predicted by the model irrespective of the impact on speed. For roadways with cameras and other types of engineering schemes, including speed limit changes, a simple relationship between the change in the mean speed and the consequent change in crashes is available. The models created in the study indicated that speed management schemes are most effective on high-speed roads: larger mean speed reductions and the overall percentage in crash reductions are achieved by programs implemented on roads with higher before mean speeds.

Hirst et al. also found that for the range of mean speeds typically found on 30 mph roads, the percentage of crash reduction per one mph of reduced speed is around 4% for roadways with cameras and 7–8% for roadways with horizontal features. While a larger percentage of crash reductions are achieved per 1 mph of reduced speed on lower-speed roads, *larger speed reductions and a larger overall percentage of crash reductions are obtained on roads with higher before mean speeds*. This would imply that speed limit reductions and enforcement as contemplated by this current task would have significant improvements in safety.

Hirst et al. noted that while the commonly quoted “5% accident reduction per 1 mph of speed reduction” is not an unreasonable generalization, it must noted that the crash reductions achieved depend on both the before mean speed and the method of speed management employed. In particular, for programs with vertical deflections, there appears to be no progressive relationship between the percentage accident reduction and the speed reduction. For other types of schemes, a larger percentage of accident/crash reductions per 1 mph of reduced speed are achieved on lower-speed roads, but the speed reductions tend to be smaller on lower-speed roads.

Speed-camera networks and speed calming lead to large, sustainable, and highly cost-effective drops in road deaths and injuries and should target entire populations, not merely high-risk subgroups or situations (Richter et al. 2006). Nevertheless, Hirst et al. concluded that although there is evidence that inappropriate speed is a major factor affecting road crash frequency and severity, the effectiveness of speed management programs in reducing speeds and crashes, and the nature of the relationship between these reductions, is not well understood.

Hirst et al. also advised that these findings must be treated with some caution. They note that cross-sectional studies of roads with different speed and crash distributions examine how differences in the distributions of speeds on different roads may affect crashes. However, since these roads have no speed management programs in place, such studies cannot examine how a specific technique may impact speeds, or how this change in speed might relate to changes in crashes. Hirst et al. further note that numerous before-and-after studies of specific speed management schemes have been published, but few have had available both crash and speed data and, until recently, none have fully separated the changes in crashes attributable to the effects of speed changes from those due to the other factors. Therefore, the true relationship between the speed changes associated with various types of speed management measures and their consequent impact on safety have yet to be established.

Speed Management and Air Quality Impact of Traffic Flow Speed

In the past five years, research on speed limit enforcement and emissions has been performed mainly in Europe. The reports reviewed described observations and data collection performed on roads in The Netherlands, Portugal, and Switzerland.

In a study by Panis et al. (2006), the effectiveness of the various types of models available to researchers to conduct studies of speed limit effects on driver behavior was investigated. The researchers concluded that a traffic micro-simulation model is able to provide the necessary estimates of driving behavior, and that driver-specific speeds can be simulated in real time. This is considered an enormous improvement compared with a single average speed for trips and road sections employed in macroscopic emission models. However, the input data required for such models are greater than for macroscopic models. In addition, validation of such detailed models is more complicated. Most of the validations to date have been conducted against the measured traffic counts and speeds. Rarely have validations been made directly on modeled acceleration and deceleration. Efforts are required to further calibrate and validate methodologies before they can be reliably used as the basis for emissions estimation.

Panis et al. concluded that, overall, while speed management efforts effectively reduce the average speed of roadway traffic, its impact on vehicle emissions is complex. Frequent acceleration and deceleration movements in a network significantly reduce the effect of the reduced average speed on emissions. The net results are that active speed management has no significant impact on pollutant emissions.

The Portuguese study pertained to a traffic signalization project on a highway. The case study site was on Highway N6 between the cities of Lisbon and Cascais. The corridor is approximately 12.5 mi (20 km) long, with two approach lanes per direction. It is located along the coast and abuts several localities. The average annual daily traffic (AADT) is 37,000 and there are zones with different speed limits; 50, 60, and 70 k/h (30, 37, and 44 mph). At the two locations that were analyzed, the speed limit was set at 70 k/h (Coelho et al. 2005).

There were 14 traffic control devices installed. The team collected signal and traffic parameters, such as length of the yellow, red, and green intervals, the approaching traffic volume and vehicle speed distribution. Field measurements of signal control and traffic stream variables were collected over several days using video cameras at two different locations for the site. Traffic volumes and speed in zones outside the influence of the signals were measured to verify whether drivers actually reduced their speed in the segments where traffic control devices are installed. The study showed that drivers did reduce their speed in the corridor.

This Portuguese observation confirms results from a Texas Transportation Institute (TTI) study performed in Houston, TX, that showed average speeds would drop if speed limits are lowered or greater controls placed on a roadway. Speed limits were reduced on several Houston roadways. The TTI study indicated that although the average speeds had been reduced, the 55 mph level was not achieved. This proved consistent for all freeways that had been monitored. On a section of the I-610 North Loop that was previously signed at 60 mph, average speeds reduced from 60.2 mph to 57.8 mph during the non-peak daytime hours. During nighttime hours, the average speed decreased from 63.5 mph to 60.8 mph. However, the new averages were still above the posted speed limit by 2.8 mph and 5.8 mph respectively. (TTI 2002) An approximately seven-mile section of US 290 east of Beltway 8 previously signed at 65 mph resulted in an approximately 5-mph reduction in average speeds. However, the observed average speeds exceeded the 55-mph limit by 4 to 7 mph. (TTI 2002)

Coelho et al. concluded that speed limit strategies that prioritize enforcement of the speed limit tend to create more stops for all traffic, and therefore produce higher emissions. The control of speed violators increases with traffic flow. As a trade-off, overall traffic delay will also increase as well as the number of vehicles that are unfairly stopped, and, as a result, increases the generation of pollutant emissions. If the intent were to minimize the emissions consequences, then a more tolerant strategy for speed enforcement would need to be adopted.

This dilemma is highlighted by a New Zealand study. Povey et al. found that the perceived risk of being caught is a major determinant of drivers’ choice of speed. Speed limit reductions on a New Zealand roadway led to decreases in crashes, but this was achieved through an increase in speed infringement notices reflecting a decrease in enforcement tolerances and a policy of issuing tickets rather than warnings. The researchers also noted that high-impact advertising and publicity campaigns to promote the harmful consequences of speeding supported enforcement activity (Povey et al. 2003).

In the Netherlands, dispersion models had suggested that traffic-related emissions on highways were substantially affected by the maximum driving speed. More strict speed limits on highways with many people living near the roadway would reduce exposure and related health effects. The objective of the Amsterdam study was to assess whether the policy to lower the maximum speed limit from 100 to 80 kph (62 to 50 mph) on a section of the Amsterdam ring highway had reduced measured traffic-related air pollution near the highway (Dijkema et al 2008).

Researchers collected traffic data from the national Department of Public Works along with roadside monitoring data from the Amsterdam Air Quality Monitoring Network. The network continuously monitors particulate matter (PM), oxides of nitrogen (NOx), and a proxy of soot at urban background and roadside locations in the Amsterdam city area. One of the roadside stations was located along the section of the ring highway under study and was where the speed limit intervention measurements were taken. The study concluded that PM emissions decreased after speeds were reduced on the section of the highway. No significant effect on NOx was observed.

In a Swiss study, Keller et al. (2008) investigated how emissions and ozone levels would have changed if the maximum speed limit on Swiss motorways were decreased from 120 to 80 kph (75 to 50 mph). The air quality model package MM5/CAMx was applied to two nested domains, both including Switzerland. Anthropogenic emissions were based on various European and Swiss data sources. The simulations for the reference case were based on current driving behavior.

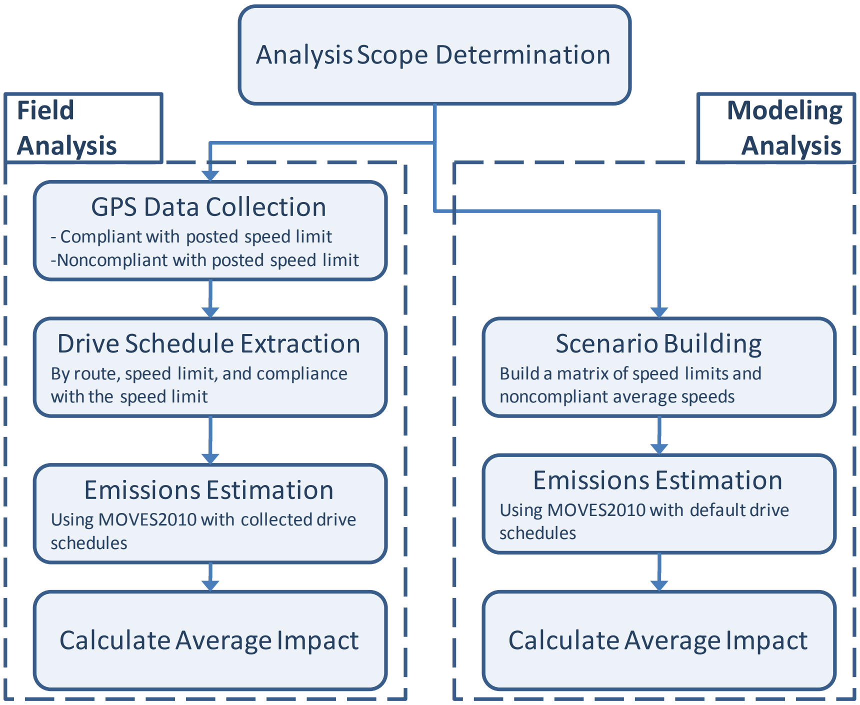
The research team concluded that the traffic speed reduction alone was not sufficient to significantly reduce ozone levels. However, it was noted that NOx and aerosol concentrations, traffic noise, and crashes decrease in such a traffic scenario as well. These provide an additional benefit besides any small ozone reduction during summer smog conditions. The researchers also noted that more important for ozone reductions in Switzerland were the long-term emission developments in Switzerland, in the adjacent countries and, to some extent, in the entire northern hemisphere. This means that significantly greater reductions would occur from more broad, regional, or international efforts.

CASE STUDIES

A field study and a modeling investigation were developed and executed to demonstrate examples of average changes in emissions of different pollutants as the results of exceeding posted speed limit. The field comprised of a limited real-world Global Positioning Satellite (GPS) data collection coupled with EPA's new emissions estimation model, the MOtor Vehicle Emission Simulator (MOVES), to determine these changes. The modeling investigation was conducted based on the MOVES default drive schedules.

The analytical approach used for this section involved the execution of four tasks. The following figure shows the analysis flow diagram, and where the various tasks fit in the process. As shown in the flow diagram, this analysis is divided into two phases that were executed in parallel — a field analysis phase based on field collected GPS data and a modeling analysis based on MOVES default drive schedules. The following section describes these tasks in detail. Both studies were performed based on the following common assumptions:

- only gasoline passenger cars and passenger trucks (SUVs, minivans, and pickup trucks)were used;
- all the vehicles use the same gasoline;
- the emissions estimations are based on average ambient conditions for Travis County, TX, in August;
- the 2009 age distribution was used for both vehicle classes; and
- a 50%-50% split was assumed for vehicle classes.



Field Study

EPA's newest emissions model, MOVES, utilizes a disaggregate approach to estimate emissions rates and emissions inventories (EPA 2009). This disaggregate approach enables MOVES to perform estimations at different analysis levels. The model is currently available with only the national average driving patterns included in the default database of the model. However, users can input customized drive schedules or equivalent operating mode distributions into the model for link-based analysis; i.e., project level analysis. This field study exploits this feature of the MOVES model by applying real-world speed profiles for scenarios representing speed limit compliant and noncompliant driving conditions.

For this purpose, the research team conducted a series of data collection efforts on a major highway in Austin, TX, metropolitan area. A mid-size passenger vehicle was equipped with a GPS unit and was driven multiple times on selected routes. The driver used the following driving instructions to generate the appropriate information for the required scenarios:

- speed limit compliant: do not exceed the speed limit while following the traffic flow in the center or right lane;
- speed limit noncompliant: follow the traffic flow in the left lane; and
- drive safely and do not interrupt the traffic flow in any instance.

All the data collection runs occurred during the off-peak period between 10:00 a.m. and 1:00 p.m. Table 1 lists the study routes and the information for the different scenario runs.

Figure 1 shows these routes on the area map. Both roadways (IH-35 and US 183) are major freeways that serve the Austin metro area. Speed limits on these roadways vary between 55 mph in urban areas to 70 mph in rural areas.

Table 1. Study Routes and Information of the Scenario Runs.

Scenario ID	Section	Distance (mi)	Posted Speed Limit (mph)	Compliant Average Speed (mph)	Noncompliant Average Speed (mph)	Extra Speed (mph)
1	**IH-35 N between US290 and exit 241**	**3.72**	60	61.2	63.4	2.2
2			60	59	67.3	8.3
3	**IH-35 N between exit 241 and exit 252**	**9.37**	65	62.8	70	7.2
4			65	64.1	68.2	4.1
5	**IH-35 S between exit 241 and exit 238B**	**3.28**	60	57.3	67.6	10.3
6			60	59.3	66.8	7.5
7	**IH-35 S between exit 252 and exit 241**	**9.44**	65	62.5	68.5	6
8			65	63	69.9	6.9
9	**US183 N between exit IH-35 and Spicewood Springs Rd.**	**9.72**	65	63.3	68.4	5.1
10	**US183 S between Spicewood Springs Rd. and IH-35**	**8.03**	65	64.2	68.5	4.3

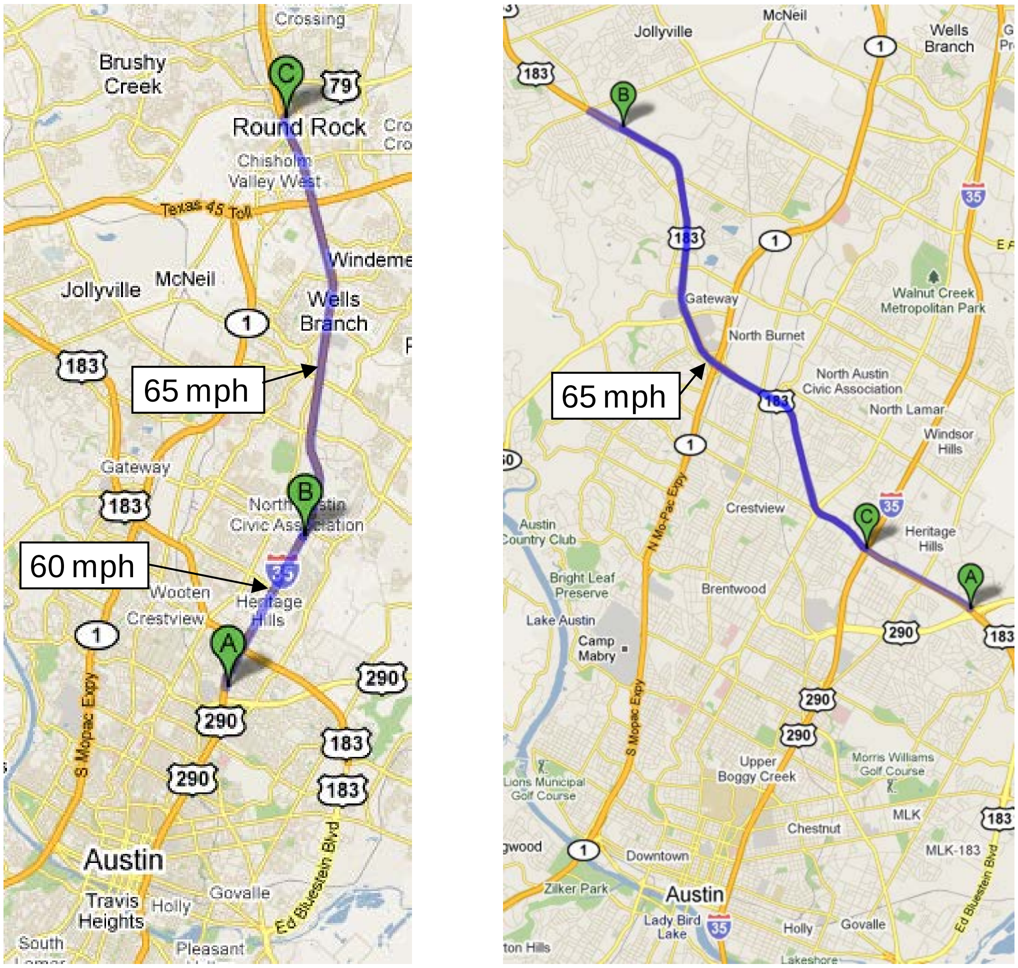


Figure 1. Study Routes – Left: IH-35, Right: US 183.

Each data collection run included driving in a loop while not exceeding the speed limit, termed as *compliant* runs, followed immediately by a run following the traffic flow on the left most lane, termed as *noncompliant* runs. Table 1 also includes the information for each run.

The GPS data file was imported into mapping software. Locations of the beginning and end points of the runs as well as the points of speed limit changes were marked on the map. The observations corresponding to each run were then extracted using these reference points. The speed profiles of all runs were examined for errors and out-of-bound readings. This quality control showed no sign of error in the extracted speed profiles and therefore each speed profile was accepted as a *drive schedule* representing one of the scenarios shown in Table 1. The table also shows average speed and traveled distance of each run. Figure 2 presents a sample of these drive schedules. Appendix A presents drive schedule graphs for the remainder of the runs.

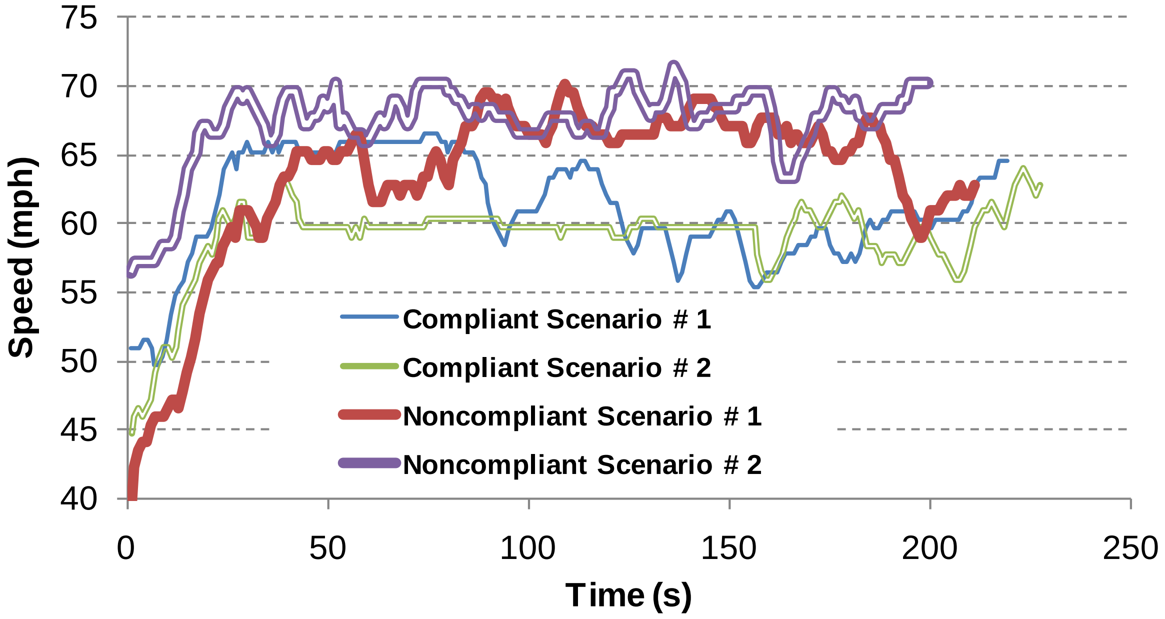


Figure 2. Drive Schedules for IH-35 N with a 60 mph Speed Limit.

The drive schedules were imported to the most recent version of the MOVES2010 model under the model's *project level* analysis option. The age distribution of Texas light-duty gasoline vehicles were also imported to the model. The ambient conditions for an average day in August were obtained and used for all the MOVES runs. MOVES has two light-duty gasoline vehicle classes: passenger cars (source type 21), and passenger trucks (source type 31) including SUVs, minivans, and pick-up trucks. Both of these classes were included in the analysis. A 50%-50% split was used to aggregate the results to represent the majority of the light-duty gasoline vehicles.

The following pollutants were included in the analysis: NOx, carbon monoxide (CO), total hydrocarbons (THC), $PM_{2.5}$, and carbon dioxide (CO_2). NOx and THC are ozone precursors and thus have high importance in Texas while CO and $PM_{2.5}$ are associated with health hazard to humans. CO_2 is the main greenhouse gas contributing to the global climate change. CO_2 is also directly related to fuel consumption and therefore its changes reflect changes in fuel consumption.

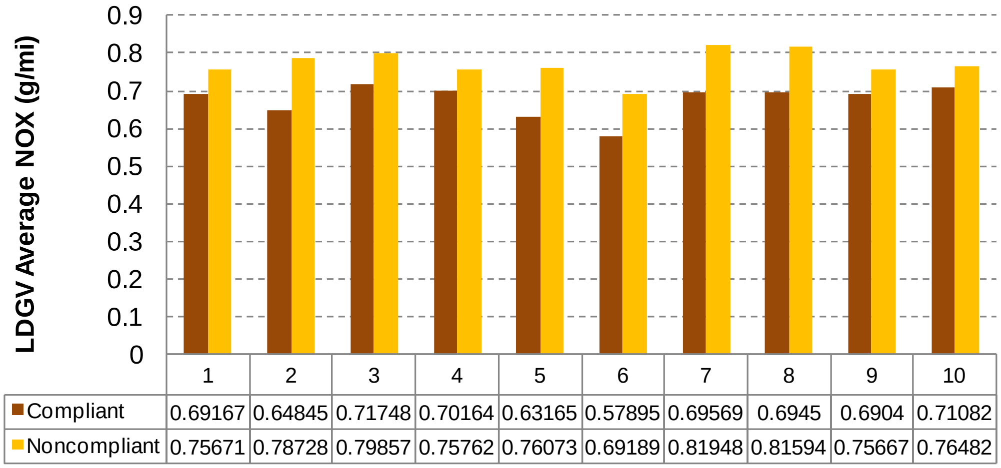
The results of the MOVES runs, grams of pollutants for each drive schedule normalized by the distance, grams per mile (g/mi) for a single representative vehicle, were calculated and organized by pollutant, scenario runs, and posted speed limits. The net difference and percentage changes in emissions for each scenario were calculated. Figure 3 through Figure 7 shows the distance-normalized emissions results of the average representative vehicle for each scenario. Appendix B contains the graphs representing emissions rates for each vehicle class, i.e., passenger cars and passenger trucks. Table 2 presents the percent changes for each scenario run for the average representative vehicle. Table 3 lists the average percentage change for each speed limit (60 and 65 mph).

Table 2. Percentage Changes in Emissions for Each Scenario.

Scenario Number	1	2	3	4	5	6	7	8	9
Posted Speed Limit (mph)	60	60	65	65	60	60	65	65	65
CO_2 Change (%)	-4.1%	2.0%	3.2%	-0.2%	3.6%	2.7%	6.4%	8.4%	3.4%
NOx Change (%)	9.4%	21.4%	11.3%	8.0%	20.4%	19.5%	17.8%	17.5%	9.6%
THC Change (%)	10.7%	20.1%	23.9%	26.0%	22.2%	21.9%	28.5%	31.7%	20.5%
PM2.5 Change (%)	10.2%	12.3%	36.6%	33.7%	23.1%	24.0%	20.9%	35.2%	27.0%
CO Change (%)	30.0%	57.7%	41.0%	57.9%	55.5%	48.7%	46.0%	66.7%	41.3%

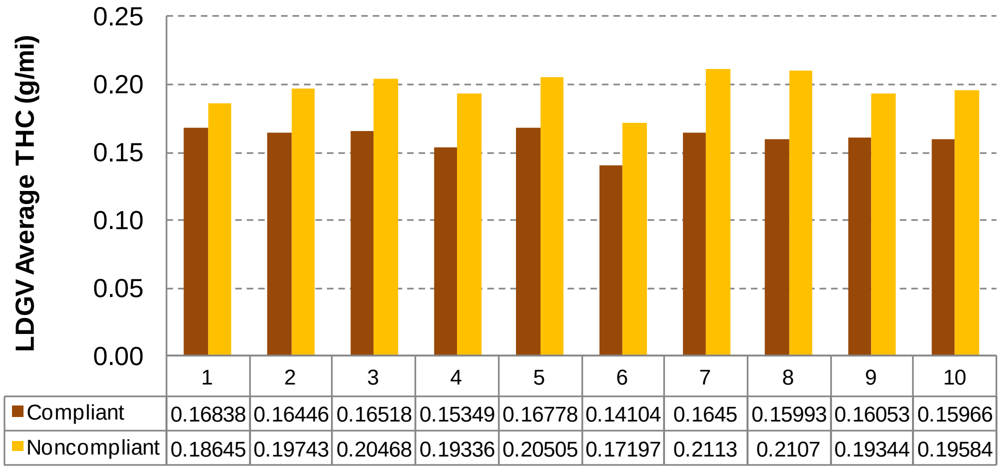
Table 3. Average Changes in Emissions as the Result of Exceeding the Speed Limit.

	65 mph speed limit	60 mph speed limit
	Average Change (%)	Average Change (%)
CO_2 Change (%)	3.9%	1.0%
NOx Change (%)	12.0%	17.7%
THC Change (%)	25.5%	18.7%
PM2.5 Change (%)	30.0%	17.4%
CO Change (%)	50.8%	48.0%



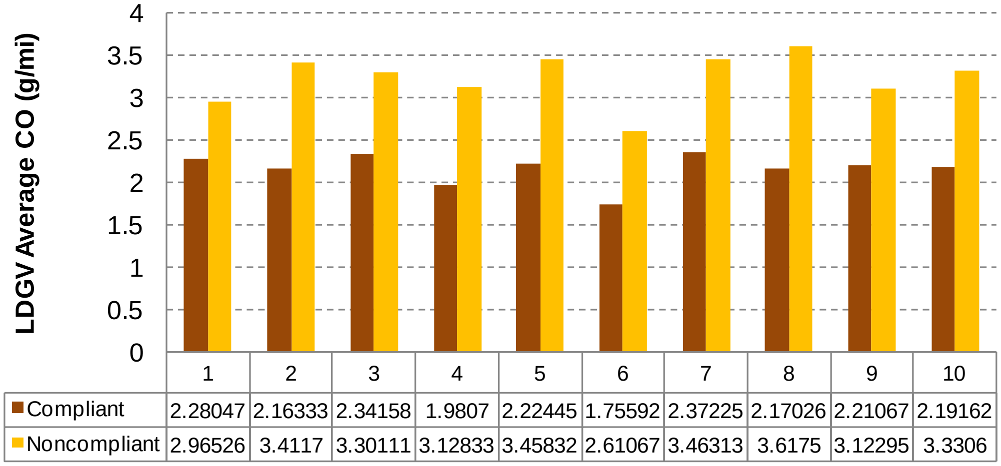
	1	2	3	4	5	6	7	8	9	10
■ Compliant	0.69167	0.64845	0.71748	0.70164	0.63165	0.57895	0.69569	0.6945	0.6904	0.71082
■ Noncompliant	0.75671	0.78728	0.79857	0.75762	0.76073	0.69189	0.81948	0.81594	0.75667	0.76482

Figure 3. NOx Emissions Rates for Different Scenarios.



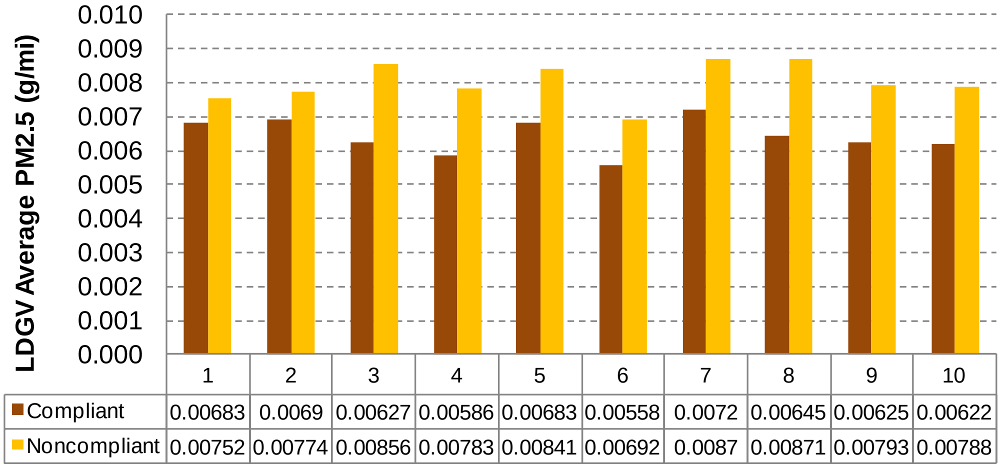
	1	2	3	4	5	6	7	8	9	10
■ Compliant	0.16838	0.16446	0.16518	0.15349	0.16778	0.14104	0.1645	0.15993	0.16053	0.15966
■ Noncompliant	0.18645	0.19743	0.20468	0.19336	0.20505	0.17197	0.2113	0.2107	0.19344	0.19584

Figure 4. THC Emissions Rates for Different Scenarios.



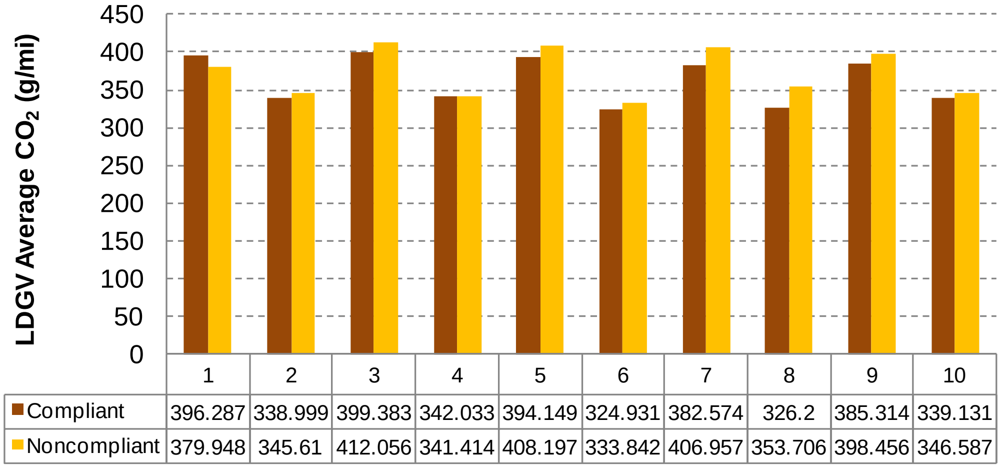
	1	2	3	4	5	6	7	8	9	10
■ Compliant	2.28047	2.16333	2.34158	1.9807	2.22445	1.75592	2.37225	2.17026	2.21067	2.19162
■ Noncompliant	2.96526	3.4117	3.30111	3.12833	3.45832	2.61067	3.46313	3.6175	3.12295	3.3306

Figure 5. CO Emissions Rates for Different Scenarios.



	1	2	3	4	5	6	7	8	9	10
■ Compliant	0.00683	0.0069	0.00627	0.00586	0.00683	0.00558	0.0072	0.00645	0.00625	0.00622
■ Noncompliant	0.00752	0.00774	0.00856	0.00783	0.00841	0.00692	0.0087	0.00871	0.00793	0.00788

Figure 6. PM2.5 Emissions Rates for Different Scenarios.



	1	2	3	4	5	6	7	8	9	10
■ Compliant	396.287	338.999	399.383	342.033	394.149	324.931	382.574	326.2	385.314	339.131
■ Noncompliant	379.948	345.61	412.056	341.414	408.197	333.842	406.957	353.706	398.456	346.587

Figure 7. CO_2 Emissions Rates for Different Scenarios.

The results show a modest increase of CO_2 for both speed limits. Fuel consumption is directly related to CO_2 and therefore will have approximately the same percentage of increase. Both ozone precursors, NOx and THC, increased more than 10% as the result of exceeding the speed limit. $PM_{2.5}$ also showed a sizeable increase in the range of 10% to 36%. With an average increase of approximately 50%, CO showed the highest increase among all the pollutants. The higher speed limit (65 mph) appears to have an increased impact on the CO_2 changes, THC, and $PM_{2.5}$; i.e., exceeding a 65 mph speed limit appears to result in a higher percentage change in emissions than exceeding a 60 mph speed limit.

A simple complementary analysis was performed to provide an estimate of the potential total impacts for different levels of noncompliance with the speed limit. Figure 8 and Figure 9 show these results. Appendix C contains these results in tabular form. These figures and their corresponding tables are intended to provide a quick estimate of the amount of overall increase in pollutant emissions as a result of exceeding the posted speed limits. A detailed analysis for a larger sample of roadways is needed to produce accurate estimates.

In interpreting and using the results of this analysis, the limitation of the collected data and methodology should be considered. The relationship between traffic movement and emissions is a multidimensional issue. The main dimensions are – traffic demand (traffic volume), – average traffic speed, and – average driving behavior (i.e., the amount of acceleration and deceleration instances). Any change in one dimension is expected to influence the other dimensions as well, which might decrease or cancel out the intended benefits of the implemented measure. For example, lowering the average traffic speed via increased speed limit enforcement might increase the average distribution of acceleration maneuvers, which in turn will produce higher amount of emissions that exceed the reductions obtained from reducing average traffic speed.

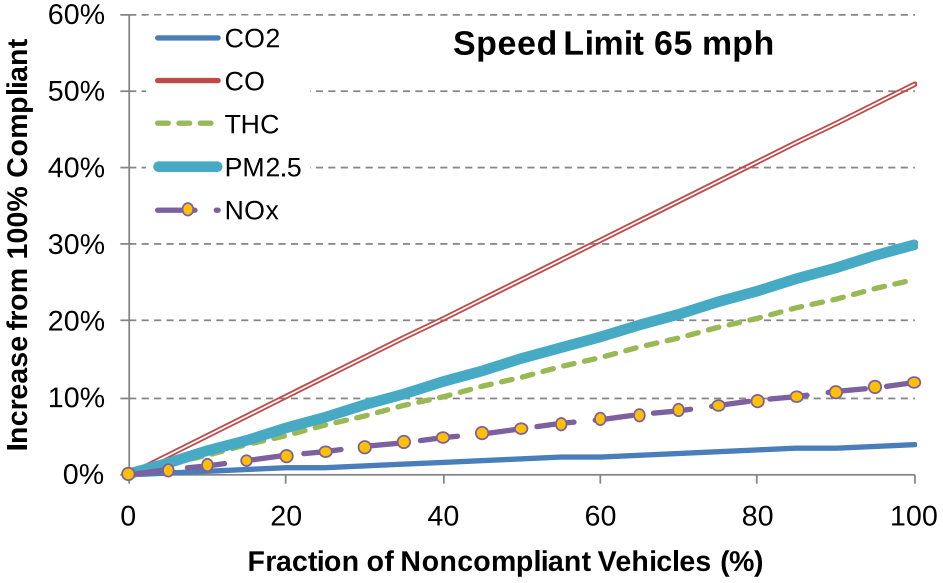


Figure 8. Estimated Total Impact for Speed Limit of 65 mph.

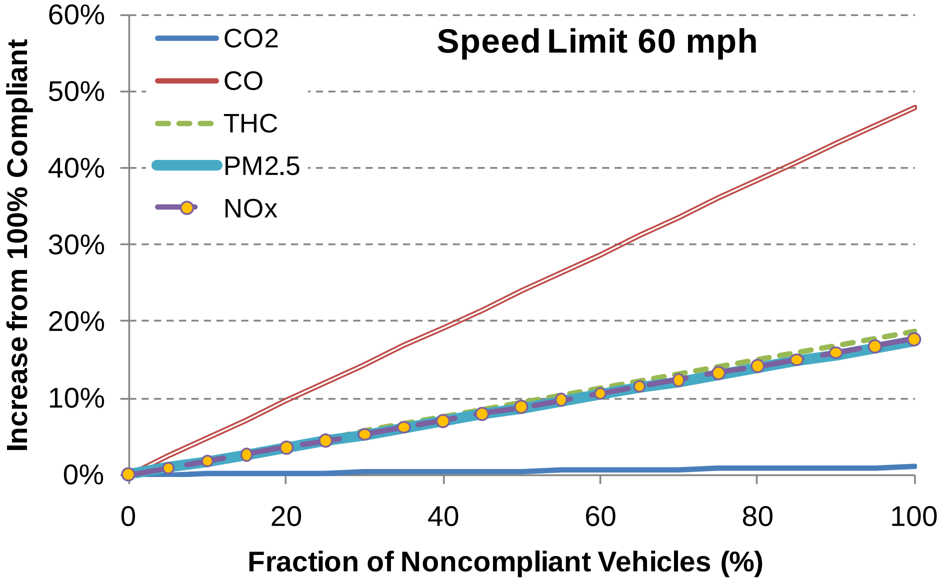


Figure 9. Estimated Total Impact for Speed Limit of 60 mph.

The data collected and used in this investigation were obtained driving a single vehicle. While this approach provided real-world driving pattern data required for accurate estimation analysis, however, it does not address the interaction of the vehicles. Specifically, it is assumed that, on average, all the vehicles will drive the same as the speed-limit-compliant driving behavior that was observed in this case study, if the posted speed limit is more effectively enforced.

MOVES Study

In addition to the field study which made use of drive schedules based on GPS data collected for case study corridors, the research team also examined the changes in emissions rates based on the default drive schedules that are incorporated in the current version of the MOVES model. These drive schedules represent national average drive schedules corresponding to different average speeds. The drive schedules are grouped by roadway type; i.e., rural or urban, and limited access (freeway and highway) or unlimited access (arterials). Since the focus of the study is the air quality impact of speed limit enforcement, the research team determined the urban limited access road type would best represent the desired conditions.

The required MOVES input files were prepared assuming the similar conditions that were used for the field study; i.e., average Texas age distribution for the light-duty gasoline vehicles, a 50%-50% split for cars and passenger trucks, etc. Similar to the field study, emissions of NOx, THC, CO, $PM_{2.5}$, and CO_2 were included in the analysis.

Using the above input information, the emissions rates for average speeds of 75, 70, 65, 60, and 55 mph were obtained for these pollutants. The percent changes in emissions rates as the result of exceeding the speed limit were calculated for 70, 65, 60, and 50 mph speed limits. For each speed limit, exceeding the speed limit by 5, 10, and 15 mph were included in the analysis where applicable. The highest speed bin in the MOVES model has an average speed of 75 mph, therefore this speed was the maximum speed included in this investigation. Table 4 shows the results of this analysis. Figure 10 through Figure 14 show the same results in graphical form.

Table 4. MOVES Emissions Rates Changes as a Result of Exceeding the Speed Limit.

Posted Speed Limit (mph)	**70**	**65**	**65**	**60**	**60**	**60**	**55**	**55**	**55**
Noncompliant Average Speed (mph)	**75**	**75**	**70**	**75**	**70**	**65**	**70**	**65**	**60**
Extra Speed (mph)	**5**	**10**	**5**	**15**	**10**	**5**	**15**	**10**	**5**
CO_2 Change (%)	5.9%	10.8%	4.6%	13.2%	6.8%	2.2%	5.6%	1.0%	-1.1%
NOx Change (%)	8.6%	17.3%	8.0%	23.6%	13.8%	5.4%	15.4%	6.8%	1.4%
THC Change (%)	14.5%	24.6%	8.8%	25.7%	9.8%	0.9%	5.9%	-2.6%	-3.5%
PM2.5 Change (%)	16.2%	28.6%	10.7%	40.0%	20.6%	8.9%	21.5%	9.7%	0.8%
CO Change (%)	44.1%	37.3%	-4.7%	78.1%	23.6%	29.7%	1.5%	6.6%	-17.9%

As previously mentioned the default drive schedules in the MOVES model for a vehicle class depends on the type of the facility and does not have any direct relationship with the speed limits. The results of this analysis should then be interpreted in light of this limitation. It is strongly recommended to take these results as an indication of the changes and not the final estimated changes. An approach similar to the field study in this project is a better method to produce accurate estimates of emissions changes. Overall, the modeling analysis results are in agreement with field observations; however, it appears that the benefits of enforcing lower speed limits (i.e. 55 and 50 mph) are not as considerable as speed limits higher than 60 mph.

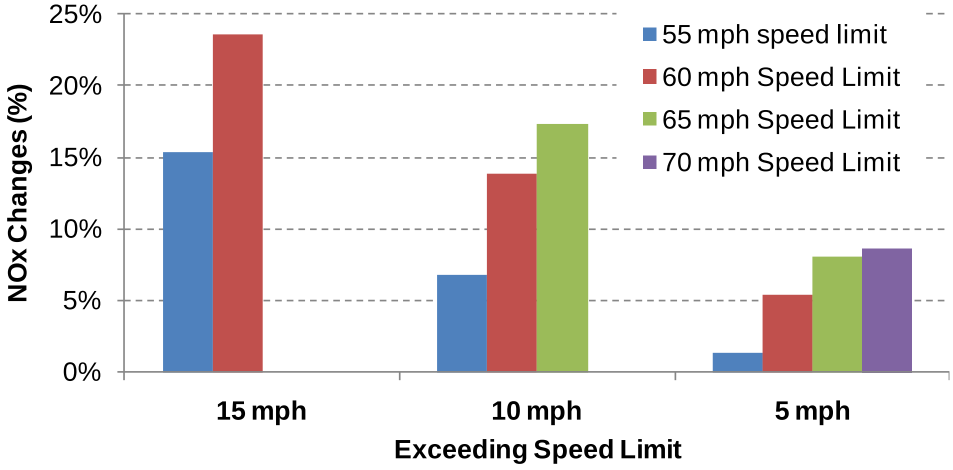


Figure 10. Changes in NOx Emissions as a Result of Exceeding the Speed Limit.

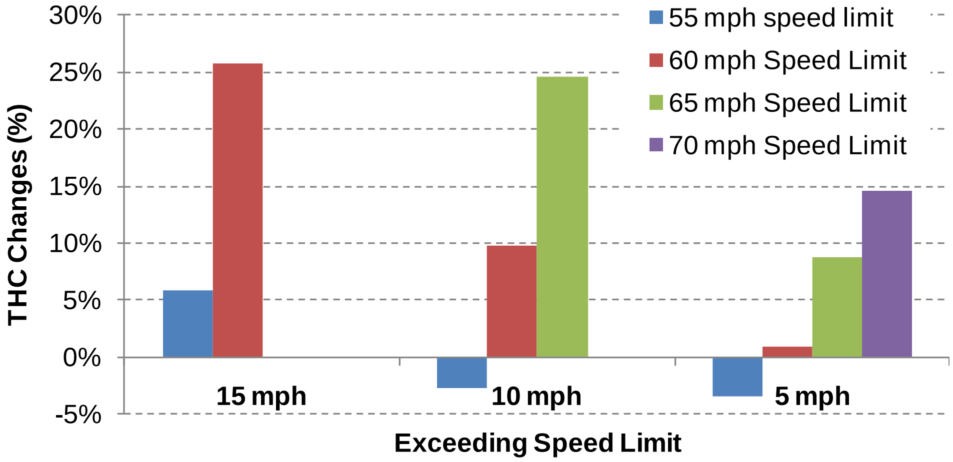


Figure 11. Changes in THC Emissions as a Result of Exceeding the Speed Limit.

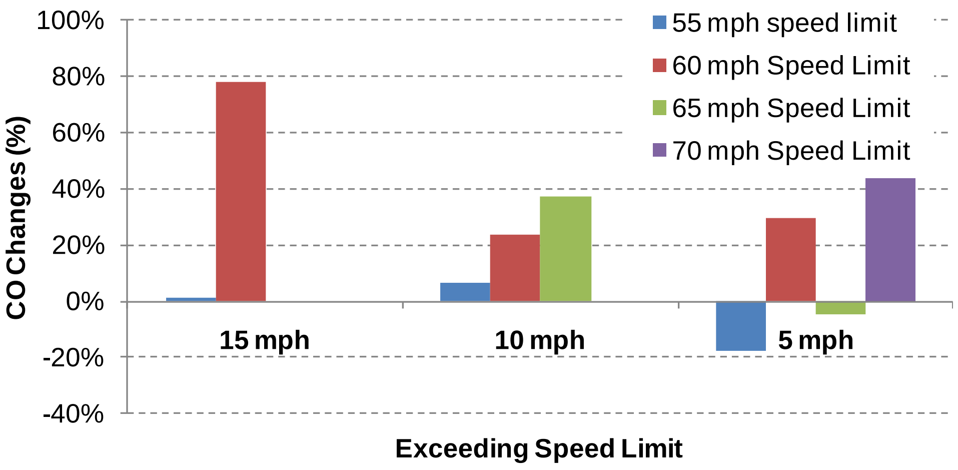


Figure 12. Changes in CO Emissions as a Result of Exceeding the Speed Limit.

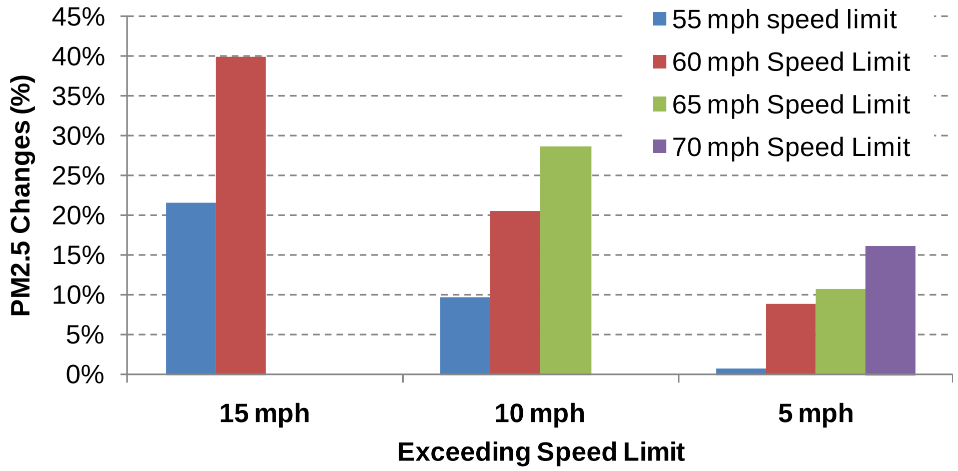


Figure 13. Changes in $PM_{2.5}$ Emissions as a Result of Exceeding the Speed Limit.

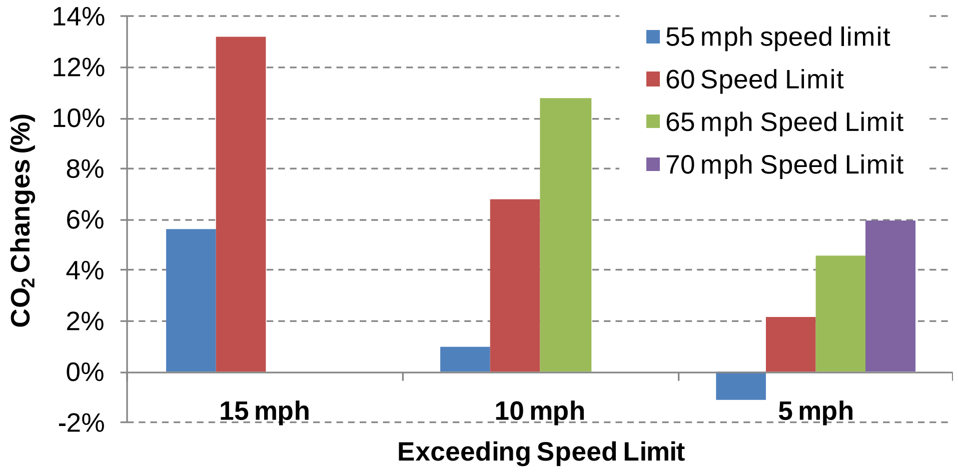


Figure 14. Changes in CO_2 Emissions as a Result of Exceeding the Speed Limit.

CONCLUSIONS AND RECOMMENDATIONS

The following are some key conclusions and recommendations from this study:

- While speed management and enforcement can effectively reduce the average speed of the roadway traffic, its impact on vehicle emissions is complex. For example, if the traffic flow experiences frequent acceleration and deceleration movements in a network, reducing the average vehicle speed may not have much of an impact on emissions. In such cases, active speed management may have no significant impact on pollutant emissions.
- In terms of additional safety benefits - it has been suggested that a correlation exists between reductions in crashes and reductions in mean speed. However, research suggests that the actual percentage of crash reduction depends on the nature of the road as well as the previous operating speeds.
- Traffic micro-simulation models have the potential to provide the necessary estimates of driving behavior and driver-specific speeds in real time. This is considered an important improvement compared with a single average speed for trips and road sections employed in macroscopic speed and emission models. However, the input data required for such models are greater than for macroscopic models.
- A case study analysis including a field study and modeling investigation using EPA's MOVES model indicated that exceeding posted speed limits can increase CO, NOx, THC, and $PM_{2.5}$ emissions from light-duty vehicles.
- Because of the complexity of the ozone formation in the atmosphere, and the characteristics of dispersion and interactions of other pollutants, the ultimate air quality benefits due to reduction or better enforcement of speed limits cannot be stated with certainty. However, it should be noted that potential benefits include reductions in ozone (especially during summer smog conditions), NOx and aerosol concentrations, traffic noise, and crashes.
- It should be noted that the results of the analyses that were conducted in this study are indicative. More data is required for checking their statistical significance. A more comprehensive study with a larger number of samples will enable researchers to conduct more detailed statistical analysis and produce accurate estimates of average emissions changes as the result of speed limit enforcement.
- The flexibility of the emissions analysis method that was used in this study enables researchers to include other vehicle types and road classes relatively easily. Heavy-duty trucks are of specific interest to the ozone nonattainment areas of Texas because they emit large portions of NOx emissions in these areas. Therefore, the study team highly recommends a follow-up data collection and analysis for a sample of heavy-duty diesel trucks traveling on urban freeways and highways.
- Additionally, the validation of such detailed emissions models is more complicated. Efforts are required to further calibrate and validate methodologies before they can be reliably used as the basis for emissions estimation.
- GPS data collection similar to what was performed in this case study is recommended in different metropolitan and non-attainment areas in the state. This will provide the basis for local analysis and more accurate estimates for those locations.

From the findings of this study, it is seen that there is a need for an easy-to-use emissions estimation tool for determining the overall effectiveness of various traffic speed reduction strategies. The data and methodologies used in this study provide the necessary materials for such an application. It is assumed that the reductions in prevailing speeds can be brought about through better speed limit enforcement, or through speed limit reduction. A longer-term case study using data obtained from before and after speed enforcement or speed reduction measures would provide better information to validate this assumption.

This research also lays the groundwork for quantifying the emissions benefit due to congestion reduction in a similar manner. By collecting drive schedule patterns for congested and uncongested travel, and making use of the same underlying principles as this task, it is possible to similarly estimate potential emissions benefits. The researchers recommend this as an additional area of study.

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APPENDIX A

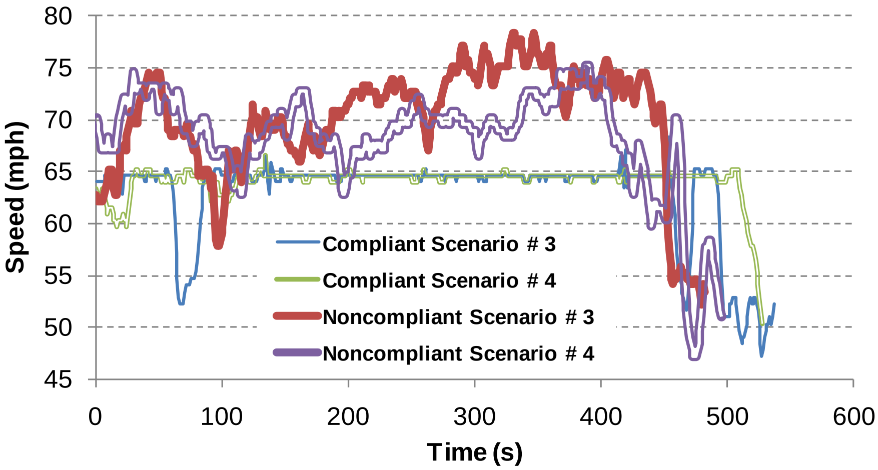


Figure A.1. Drive Schedules for IH-35 N with 65 mph Speed Limit.

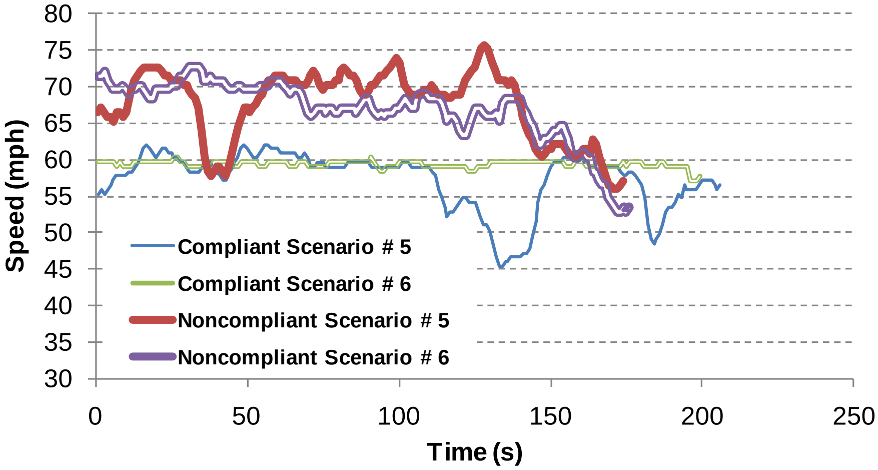


Figure A.2. Drive Schedules for IH-35 S with 60 mph Speed Limit.

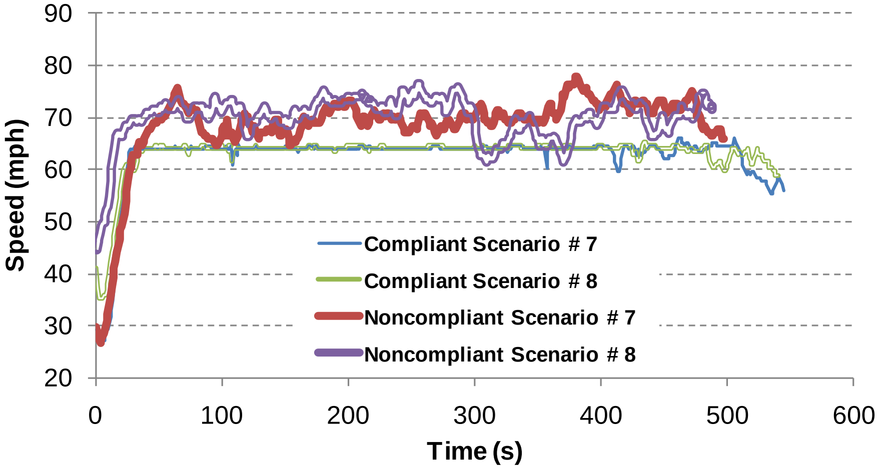


Figure A.3. Drive Schedules for IH-35 S with 65 mph Speed Limit.

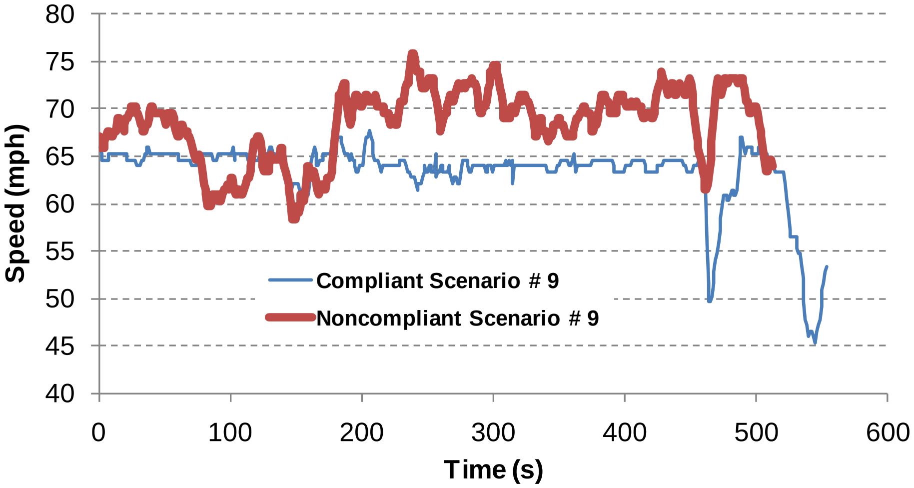


Figure A.4. Drive Schedules for US 183 N with 65 mph Speed Limit.

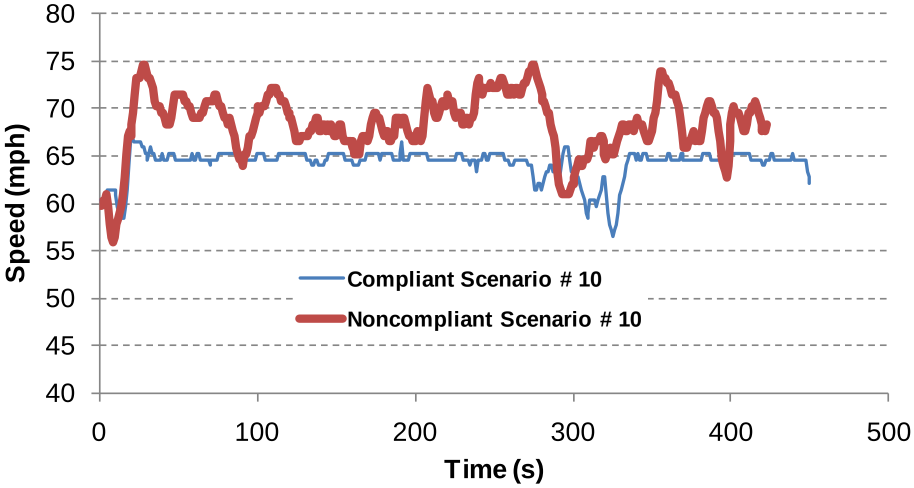
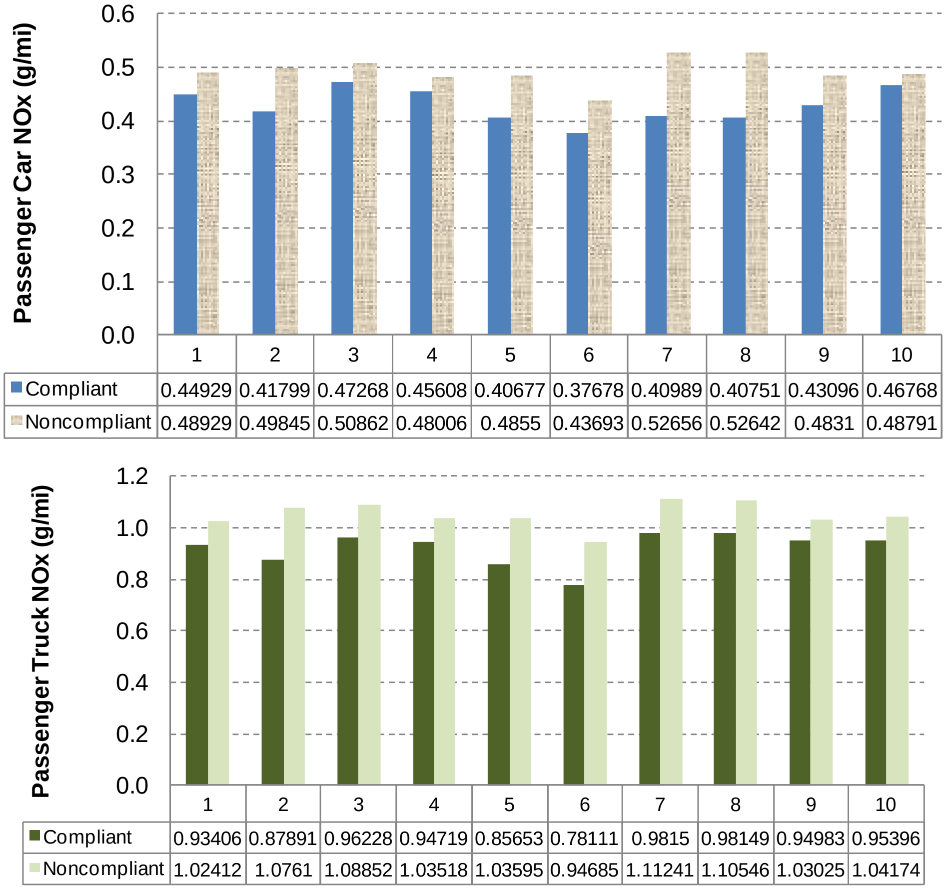


Figure A.5. Drive Schedules for US 183 S with 65 mph Speed Limit.

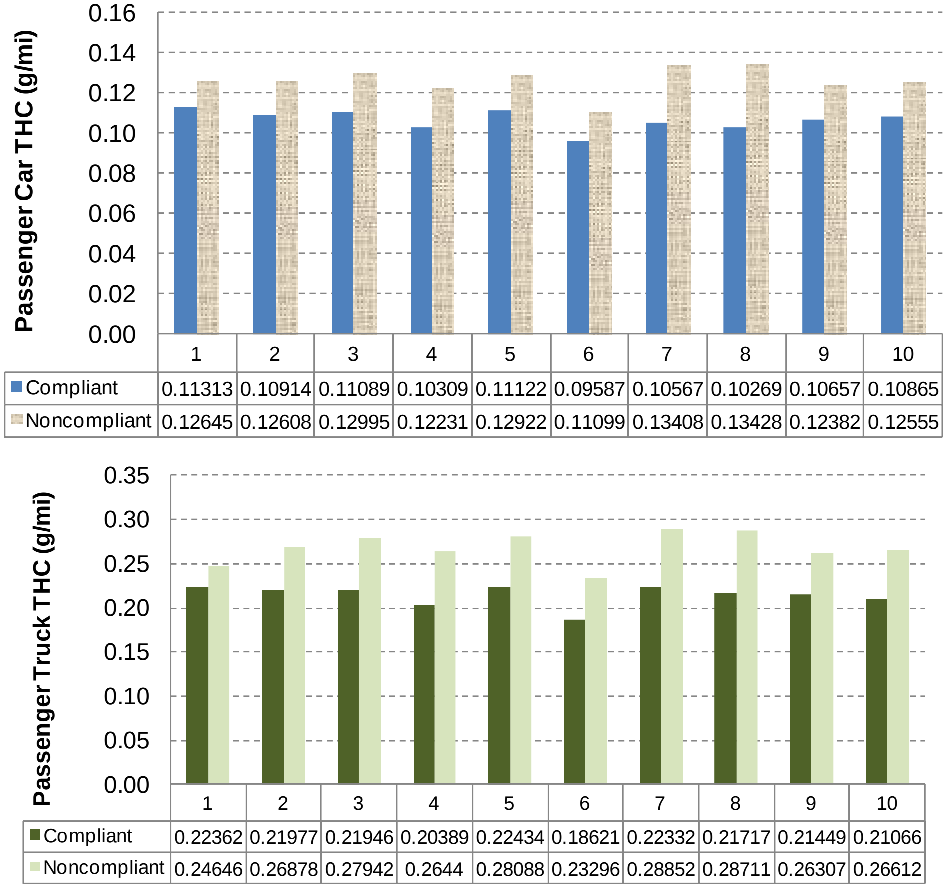
APPENDIX B



	1	2	3	4	5	6	7	8	9	10
■ Compliant	0.44929	0.41799	0.47268	0.45608	0.40677	0.37678	0.40989	0.40751	0.43096	0.46768
▨ Noncompliant	0.48929	0.49845	0.50862	0.48006	0.4855	0.43693	0.52656	0.52642	0.4831	0.48791

	1	2	3	4	5	6	7	8	9	10
■ Compliant	0.93406	0.87891	0.96228	0.94719	0.85653	0.78111	0.9815	0.98149	0.94983	0.95396
■ Noncompliant	1.02412	1.0761	1.08852	1.03518	1.03595	0.94685	1.11241	1.10546	1.03025	1.04174

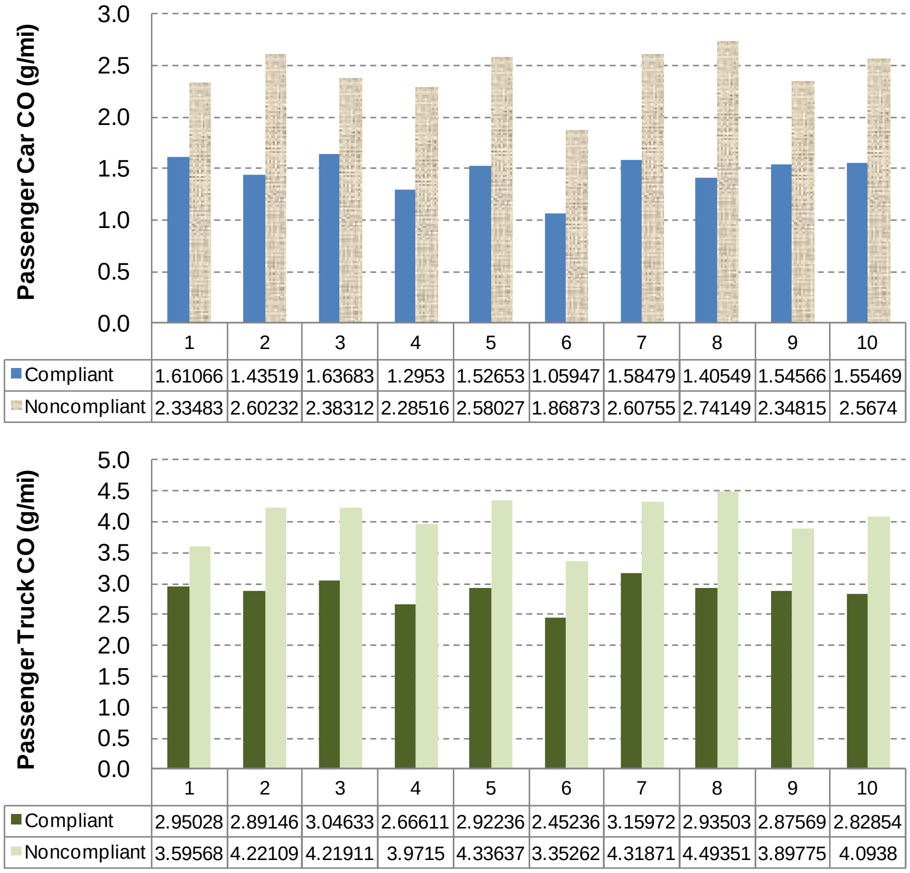
Figure B.1. NOx Emissions Rates for Different Scenarios.



	1	2	3	4	5	6	7	8	9	10
■ Compliant	0.11313	0.10914	0.11089	0.10309	0.11122	0.09587	0.10567	0.10269	0.10657	0.10865
▨ Noncompliant	0.12645	0.12608	0.12995	0.12231	0.12922	0.11099	0.13408	0.13428	0.12382	0.12555

	1	2	3	4	5	6	7	8	9	10
■ Compliant	0.22362	0.21977	0.21946	0.20389	0.22434	0.18621	0.22332	0.21717	0.21449	0.21066
■ Noncompliant	0.24646	0.26878	0.27942	0.2644	0.28088	0.23296	0.28852	0.28711	0.26307	0.26612

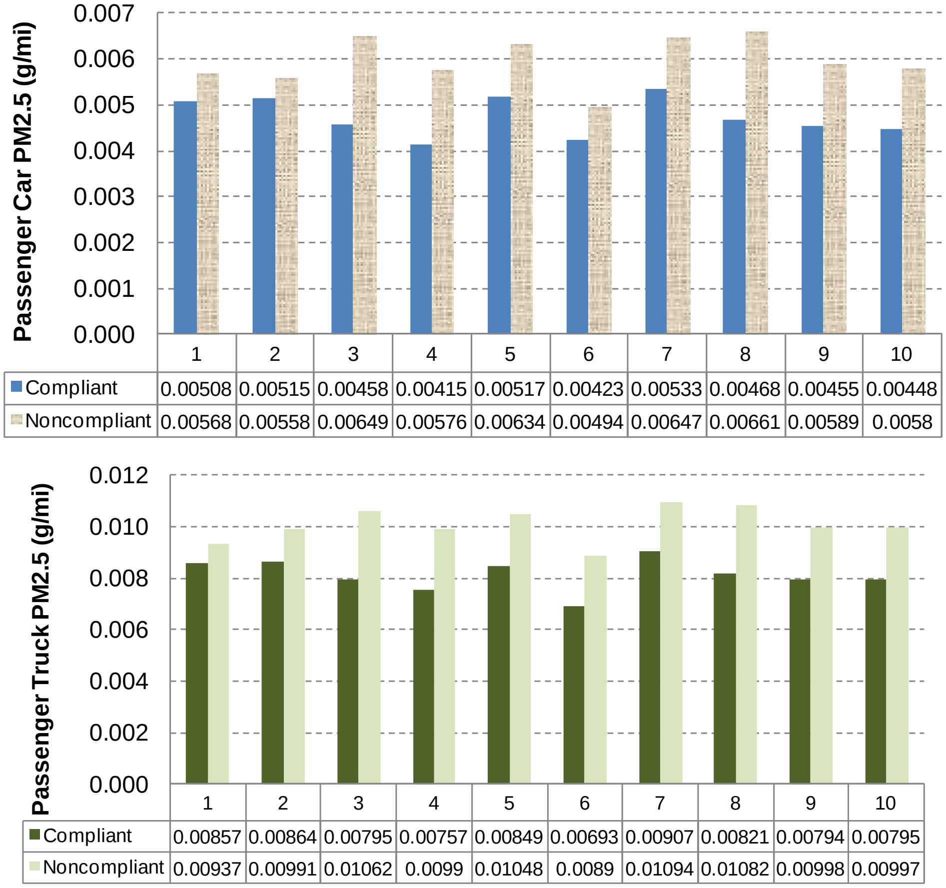
Figure B.2. THC Emissions Rates for Different Scenarios.



	1	2	3	4	5	6	7	8	9	10
Compliant	1.61066	1.43519	1.63683	1.2953	1.52653	1.05947	1.58479	1.40549	1.54566	1.55469
Noncompliant	2.33483	2.60232	2.38312	2.28516	2.58027	1.86873	2.60755	2.74149	2.34815	2.5674

	1	2	3	4	5	6	7	8	9	10
Compliant	2.95028	2.89146	3.04633	2.66611	2.92236	2.45236	3.15972	2.93503	2.87569	2.82854
Noncompliant	3.59568	4.22109	4.21911	3.9715	4.33637	3.35262	4.31871	4.49351	3.89775	4.0938

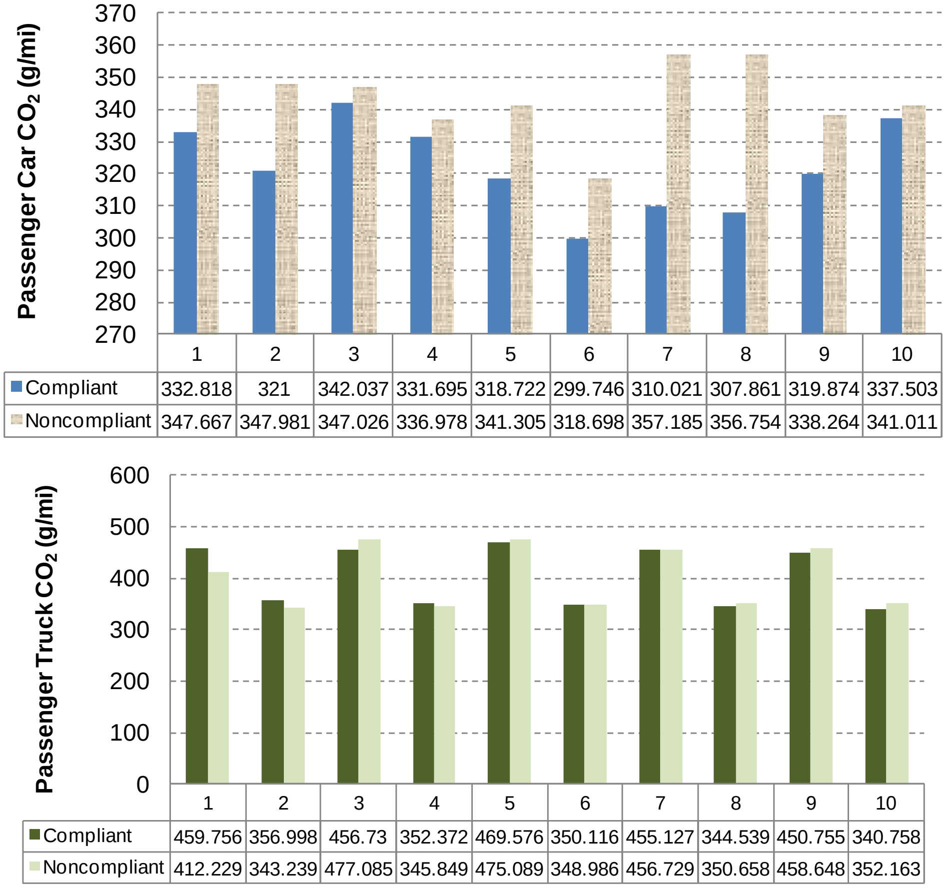
Figure B.3. CO Emissions Rates for Different Scenarios.



	1	2	3	4	5	6	7	8	9	10
Compliant	0.00508	0.00515	0.00458	0.00415	0.00517	0.00423	0.00533	0.00468	0.00455	0.00448
Noncompliant	0.00568	0.00558	0.00649	0.00576	0.00634	0.00494	0.00647	0.00661	0.00589	0.0058

	1	2	3	4	5	6	7	8	9	10
Compliant	0.00857	0.00864	0.00795	0.00757	0.00849	0.00693	0.00907	0.00821	0.00794	0.00795
Noncompliant	0.00937	0.00991	0.01062	0.0099	0.01048	0.0089	0.01094	0.01082	0.00998	0.00997

Figure B.4. PM$_{2.5}$ Emissions Rates for Different Scenarios.



	1	2	3	4	5	6	7	8	9	10
■ Compliant	332.818	321	342.037	331.695	318.722	299.746	310.021	307.861	319.874	337.503
▨ Noncompliant	347.667	347.981	347.026	336.978	341.305	318.698	357.185	356.754	338.264	341.011

	1	2	3	4	5	6	7	8	9	10
■ Compliant	459.756	356.998	456.73	352.372	469.576	350.116	455.127	344.539	450.755	340.758
■ Noncompliant	412.229	343.239	477.085	345.849	475.089	348.986	456.729	350.658	458.648	352.163

Figure B.5. CO$_2$ Emissions Rates for Different Scenarios.

APPENDIX C

Figure C.1. Estimated Total Impact for a Speed Limit of 65 mph.

	65 mph Speed Limit				
	Change from 100% compliant				
Noncompliant Fraction	**CO2**	**CO**	**THC**	**NOx**	**PM2.5**
(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
0	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.2%	2.5%	1.3%	0.6%	1.5%
10	0.4%	5.1%	2.6%	1.2%	3.0%
15	0.6%	7.6%	3.8%	1.8%	4.5%
20	0.8%	10.2%	5.1%	2.4%	6.0%
25	1.0%	12.7%	6.4%	3.0%	7.5%
30	1.2%	15.2%	7.7%	3.6%	9.0%
35	1.4%	17.8%	8.9%	4.2%	10.5%
40	1.6%	20.3%	10.2%	4.8%	12.0%
45	1.8%	22.9%	11.5%	5.4%	13.5%
50	2.0%	25.4%	12.8%	6.0%	15.0%
55	2.1%	27.9%	14.0%	6.6%	16.5%
60	2.3%	30.5%	15.3%	7.2%	18.0%
65	2.5%	33.0%	16.6%	7.8%	19.5%
70	2.7%	35.6%	17.9%	8.4%	21.0%
75	2.9%	38.1%	19.2%	9.0%	22.5%
80	3.1%	40.6%	20.4%	9.6%	24.0%
85	3.3%	43.2%	21.7%	10.2%	25.5%
90	3.5%	45.7%	23.0%	10.8%	27.0%
95	3.7%	48.3%	24.3%	11.4%	28.5%
100	3.9%	50.8%	25.5%	12.0%	30.0%

Figure C.2. Estimated Total Impact for a Speed Limit of 60 mph.

	60 mph Speed Limit				
	Change from 100% compliant				
Noncompliant Fraction	**CO2**	**CO**	**THC**	**NOx**	**PM2.5**
(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
0	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.1%	2.4%	0.9%	0.9%	0.9%
10	0.1%	4.8%	1.9%	1.8%	1.7%
15	0.2%	7.2%	2.8%	2.7%	2.6%
20	0.2%	9.6%	3.7%	3.5%	3.5%
25	0.3%	12.0%	4.7%	4.4%	4.3%
30	0.3%	14.4%	5.6%	5.3%	5.2%
35	0.4%	16.8%	6.6%	6.2%	6.1%
40	0.4%	19.2%	7.5%	7.1%	7.0%
45	0.5%	21.6%	8.4%	8.0%	7.8%
50	0.5%	24.0%	9.4%	8.8%	8.7%
55	0.6%	26.4%	10.3%	9.7%	9.6%
60	0.6%	28.8%	11.2%	10.6%	10.4%
65	0.7%	31.2%	12.2%	11.5%	11.3%
70	0.7%	33.6%	13.1%	12.4%	12.2%
75	0.8%	36.0%	14.0%	13.3%	13.0%
80	0.8%	38.4%	15.0%	14.2%	13.9%
85	0.9%	40.8%	15.9%	15.0%	14.8%
90	0.9%	43.2%	16.9%	15.9%	15.7%
95	1.0%	45.6%	17.8%	16.8%	16.5%
100	1.0%	48.0%	18.7%	17.7%	17.4%