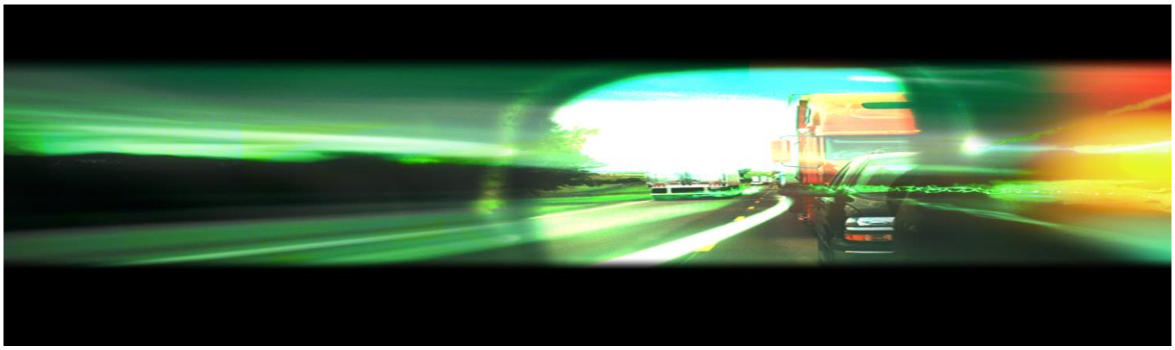
CALIBRATION OF MULTI-SCALE ENERGY AND EMISSION MODELS

Final Report



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16. Abstract

The main objective of this work is to provide a better understanding of the fuel consumption and environmental costs of vehicle operations at signalized intersection approaches. The analysis was done using advanced engine modeling software. Four different driving modes were compared: idling, cruising at different operating speeds, speed, accelerating from a stopped condition to a target operating speed, and accelerating from a non-zero speed to a target operating speed. The results of this analysis show that fuel consumption and the environmental costs of stops and delays at signalized intersection approaches are highly correlated to the corridor operating speed. Another factor that significantly impacts the fuel consumption and environmental costs at signalized intersection approaches is the drivers' acceleration patterns. Aggressive driving with high acceleration rates yields significantly higher fuel consumption and emission rates because of the high fuel/air ratio needed for this type of aggressive accelerations. Intersection and corridor control plans that are aimed to minimizing stops at approaches with high operating speed and driver educating campaigns to reduce aggressive accelerations can lead to a significant reduction in the fuel consumption and environmental costs of vehicle operations at signalized intersection approaches.

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EXECUTIVE SUMMARY

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The results of this analysis show that fuel consumption and the environmental costs of stops and delays at signalized intersection approaches are highly correlated to the corridor operating speed. While corridor traffic in small and medium size cities does not experience the high levels of congestion typically present in large urban areas, it generates a considerable amount of emissions and vehicle pollutants that has a negative impact on the environment.

Another factor that significantly impacts the fuel consumption and environmental costs at signalized intersection approaches is the drivers' acceleration patterns. Aggressive driving with high acceleration rates yields significantly higher fuel consumption and emission rates because of the high fuel/air ratio needed for this type of aggressive accelerations. Intersection and corridor control plans aimed at minimizing stops at approaches with high operating speeds and public awareness campaigns about the high cost of aggressive driving practices can contribute significantly to the reduction of corridor fuel consumption and environmental cost.

1.0 DESCRIPTION OF PROBLEM

1.0 Overview and Introduction

The main objective of this work is to quantify the fuel consumption and environmental costs of vehicle operations at signalized intersection approaches using advanced engine modeling software (GT-Suite). Four different vehicle modes of operation are considered:

- vehicles in idle mode (stopped vehicles),
- vehicles cruising at constant speed (non-stopped vehicles),
- vehicles accelerating from a stopped position to a target speed (astooped vehicle departing the interscetion approach at the onset of the green display),
- vehicles accelerating from a non-zero speed to a target speed (vehicles delayed at the intersection approach).

To account for different driver behaviors, three different acceleration modes are considered in the analysis: mile acceleration (4.7 ft. /seccond^2), normal acceleration (7.1 ft. /second^2), and aggressive acceleration (11.8 ft. /second.^{2}). These acceleration values were obtained from previous studies, *(1)* and *(2)*, which specified mild, normal, and aggressive acceleration values as the 40 %, 60 %, and 100% of the maximum vehicle acceleration envelope. In addition to the fuel consumption values, the following three vehicle pollutants are considered in the study: Nitrogen Oxides (NO_x), HydroCarbon emissions (HC), and Carbon Monoxide (CO).

This paper is organized into the following sections. After this introduction, section two documents a brief literature review of related studies. Details of the GT-Suite advanced engine modeling software are presented in section 3. The analysis procedure are summarized in section 4 followed by a documentation of the analysis results in section 5. Finally, the conclusions and recommendations for this work are presented and discussed in section 6.

2.0 APPROACH AND METHODOLOGY

2.1 Literature Review

Ahn et al. used instantaneous speed and acceleration behaviors to estimate fuel consumption and emissions (3). Test vehicles were used to verify the range of estimated values. Emission and fuel consumption rates were estimated along a range of accelerations at corresponding speeds and regression models were formalized. Emission rates were found to be the highest at high acceleration rates, traveling at speeds around 25 mph and 40 mph.

Rakha and Ding studied the impact of vehicle-stops on fuel consumption and emissions *(4)*. The authors found that fuel consumption rates are more sensitive to cruise-speed levels compared to vehicle stops. Another result showed that acceleration and deceleration rates employed during a stopping maneuver had a significant effect on emission rates. The authors used VT-Micro, a microscopic traffic simulation model, and data collected at the Oak Ridge National Laboratory in the analysis. A vehicle-stop, especially one interrupting high cruise-speeds, was shown to cause a considerable increase in fuel consumption and emission rates. The authors presented the scenario that if the speed limit along an arterial is increased from 55 mph to 65 mph, and a stop maneuver is executed, HC, CO, and NO_x emissions may increase by 60 %, 80 %, and 40 %, respectively.

Pandian et al. studied the role of traffic, road, and vehicle characteristics that affect emissions at signalized intersections *(5)*. The authors concluded that combining emission and flow models ensures a more realistic estimate for all location features and environmental parameters.

2.2 The Need for Engine Modeling ANALYSIS

GT- Suite is an engine modeling tool produced by Gamma Technologies (GTI) *(6)*. It offers versatile simulation of vehicles with conventional, Hybrid-Electric (HEV), or Electric-only (EV) drivelines, as well as the control systems and strategies key to the operation of these vehicles. Using engine modeling tools, such as GT-Suite, will provide more in-depth understanding of emissions and fuel consumptions that result from different modes of vehicle operations at different segments of the roadway network. It will also show how fuel consumption and emissions vary under different driving conditions.

2.3 Standard Driving Cycles

Figue 1 presents different dring ccyles commonly used in Europe and in North America. As can be seen in **FIGURE 1**, while many of these standard driving cycles include several stoppage and acceleration scenarios, none of them exclusively and thoroughly covers all parameters of vehicle operations at signalized intersection approaches such as the wide ranges of initial and target speeds and acceleration modes. Examples of some of the standard driving cycles presented in **FIGURE 1** include:

- FTP 75: The Federal Test Procedure. This cycle was designed in the late 1960s to ensure that newly manufactured light duty vehicles comply with emission standards and then are eligible for certification. There are three main components of the FTP cycle. These components are the cold-start, stabilized, and a hot start components.
- US06 - Supplemental FTP: high acceleration aggressive driving schedule. This cycle is covering the high-acceleration, the high-speed, or both of these driving styles. It covers the aggressive driving styles, and it deals with some of the limitations in the original FTP driving cycle.
- SC03: Supplemental Federal Test Procedure (SFTP) with Air Conditioning.
- NYCC: The New York City Cycle. This cycle deals mainly with frequent stops, low speeds, and general congested urban driving conditions.
- HWFET: Highway Fuel Economy Test Cycle.
- HHDDT: Heavy Heavy-Duty Diesel Truck Driving Cycle.
- LA92SDDS & LA92DDS: Unified Dynamometer Driving Schedule.
- IM240: EPA Inspection & Maintenance Driving Cycle / the shorten FTP driving cycle. Its main use is to check whether the light duty vehicles fulfill the emission standards.
- NEDC: The New European Driving Cycle.
- ARTEMS Motorway, ARTEMS Motorway 130, ARTEMIS_Road, Artemis_Urban: Driving Cycles developed within the (Assessment and Reliability of Transport Emission Models and Inventory Systems) project.

A full documentation and description of these standard driving cycles are documented in several references like *(7)*, *(8)*, *(9)*, and *(10)*.

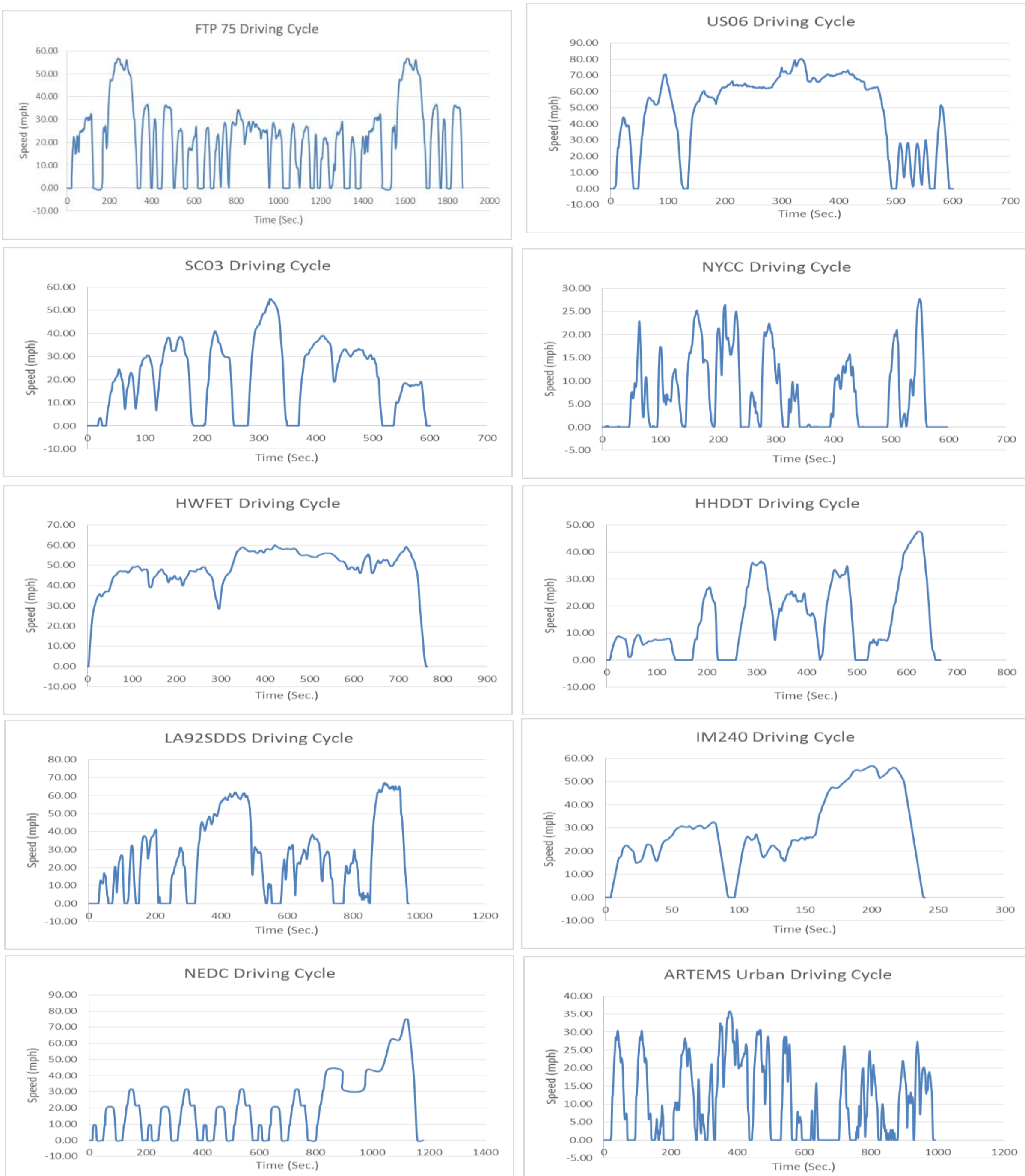


FIGURE 1 Standard common driving cycles - Sources: *(7)*, *(8)*, *(9)*, and *(10)*

The GT-Suite analysis conducted as part of this study is intended to provide an in-depth analysis of the fuel consumption and environmental costs of vehicle operations at signalized intersection approaches. While all the fuel consumption and emissions data presented in this work are for an average four-cylinder 2000 cubic centimeters gasoline engine with automatic transmission, the result trends can be generalized to cover the six-cylinder and eight-cylinder gasoline engines with a different engine size capacity and transition configurations.

2.4 GT-Suite – An Overview

GT- Suite is an engine modeling tool produced by Gamma Technologies (GTI) *(6)*. It offers versatile simulation of vehicles with conventional, Hybrid-Electric (HEV), or Electric-only (EV) drivelines, as well as the control systems and strategies key to the operation of these vehicles. GT-Suite has been used in several research fields. In *(11)*, a fully integrated model is presented utilizing the GT-Suite commercial code containing a diesel engine system model that evaluates different system and component concepts regarding their influence on fuel consumption and emissions. In *(13)*, a design of gas mixer and a simulation of dual fuel (Diesel- Compressed Natural Gas (CNG)) engine for performance parameters to examine the Brake Specific Fuel Consumption (BSFC) using GT-suite is presented. GT-Suite is also used in *(14)*, *(15)*, and *(16)*.

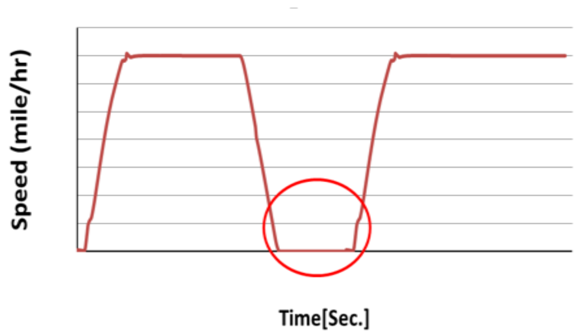
In order to investigate the effect of idling and cruising speed, specifications matching the characteristics of an average four-cylinder vehicle similar to those used in many urban and suburban areas were used. Specifically, the engine and vehicle specification inputs for the GT-Suite model were: engine configuration: naturally aspirated four-stroke with inline four-cylinder and direct injection; transmission: automatic; displacement: two liters; minimum operating speed: 950 revolutions per minute (RPM); fuel density: 756 kg/m^3; vehicle weight: 1800 kg; vehicle rolling resistance coefficient: 0.01; vehicle drag coefficient: 0.32; and final vehicle frontal area: 0.8 m^2.

2.5 Analysis Procedure

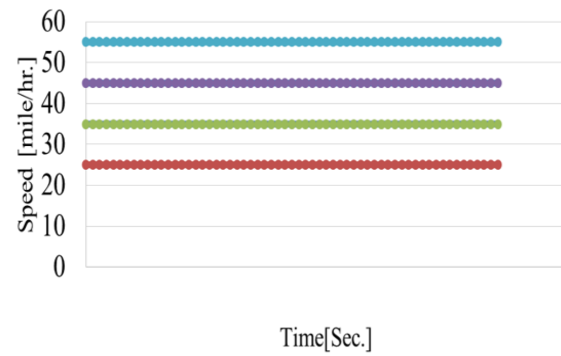
Because standardized driving cycles do not cover all parameters of vehicle operations such as the wide ranges of initial and target speeds and acceleration modes, four different operation modes were considered to be used in the GT - Suite:

- Idling: representing the case of a vehicle stopped at an intersection approach. Idling time for this case is 90 seconds (**FIGURE 2**-A).
- Cruising speed: representing the case of a non-stopped vehicle traveling through the intersection approach at constant speeds. Four cruising speeds are modeled in this analysis: 25 mph, 35 mph, 45 mph, and 55 mph. Cruising time for all of these cases is 90 seconds (**FIGURE 2**-B).
- Accelerating from zero mph to a target speed: representing the case of a vehicle stopped at an intersection approach and accelerating back to its target driving speed. Four target speeds are modeled in this analysis: 25 mph, 35 mph, 45 mph, and 55 mph with three different acceleration values for each one (**FIGURE 2**-C).
- Accelerating from a speed different from zero speed to a target speed: representing a delayed vehicle at an intersection approach by the presence of a queue at the intersection approach accelerating back to its target speed. Four different initial speed values are used in the analysis five mph, 10 mph, 15 mph, and 20 mph,) with target speeds of 25, 35, 45, and 55 mph, with three different acceleration values for each one (**FIGURE 2**-D).

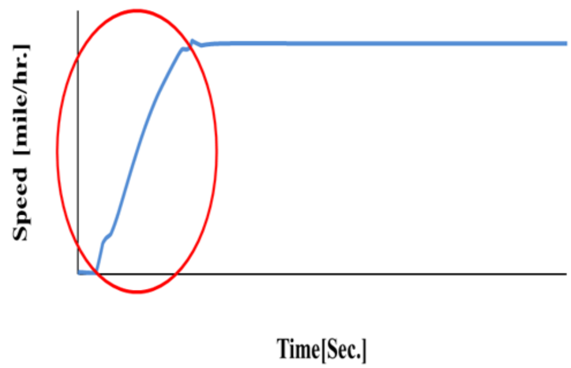
Three different acceleration values were used in the analysis to account for different driver behaviors. These three acceleration values are: mild acceleration (4.7 ft. /sec.^{2}), normal acceleration (7.1 ft. /sec.^{2}), and aggressive acceleration (11.8 ft. /sec.^{2}).



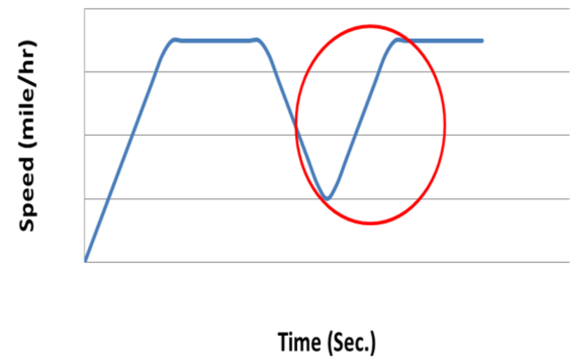
A: CASE 1: Idling (stopping at an intersection).



B: CASE 2: Cruising at 25, 35, 45, and 55 mph.



C: CASE 3: Accelerate from zero mph to (25, 35, 45, and 55 mph) with three different acceleration values for each one (12 different sub-cases).



D: CASE 4: Accelerate from (five, 10, 15, and 20 mph) to (25, 35, 45, and 55 mph) while driving on normal acceleration mode. (16 different sub-cases).

FIGURE 2 Different speed profile categories.

3.0 FINDINGS; CONCLUSIONS; RECOMMENDATIONS

3.1 Results of Quantifying Fuel Consumptions and Emission Models in Depth

3.2 Cases One and Two: The Impact of Idling and Cruising Speeds on Fuel Consumption and Emissions:

The GT-Suite model simulated the idling and cruising for a period of 90 seconds. The cruising speeds were 25, 35, 45, and 55 mph. **FIGURE 3** and **FIGURE 4** present the fuel consumption and emission rates and total amounts of the fuel consumption and emissions of cases one and two (idling and cruising).

FIGURE 3 and **FIGURE 4** show that:

- Fuel consumption rates stay constant during the 90 seconds modelling times.
- Cruising speeds of 35 mph result in less fuel consumption and fewer emissions compared to cruising at 25 mph and 45 mph, so the optimum fuel consumption rate is occurs at a cruising speed of 35 mph. This is because the used engine is a typical passenger car engine that has a small engine displacement which is intend to create this kind of behavior for vehicles used mostly in city driving modes. These city driving modes are when the normal driving speeds are around 35 mph to improve fuel economy and reduce emissions. The results of running the GT-Suite found that at 35 mph the engine ran at a higher gear than at 25 mph, and this higher gear caused the engine to perform on lower Revolutions Per Minute (RPM.) These lower engine loads at 35 mph resulted in a fuel consumption rate to be lower than the 25 mph cruising speeds.
- This result is widely recognized and was noticed in the literature *(17)* and *(18)*. As could be seen in **FIGURE 3**, increasing the running speed from 35 mph to 45 mph would result in increasing the fuel consumption rate with a percentage of 54.74, while increasing the running speed from 35 mph to 55 mph would increase the fuel consumption rate by 65.80%.
- The NOx emission rates behaved in a similar way to the fuel consumption rates with lower values for idling and at 35 mph cruising speed compared to other cruising speeds. Increasing the running speed from 35 mph to 45 mph would result in a NOx emission rate increase of 54.92%, while increasing the running speed from 35 mph to 55 mph would increase the NOx emission rate by 65.84%.
- The HC and CO emissions reported lower rates in the case of 45 and 55 mph cruising speeds compared to idling and the 35 mph cruising speed. This is because of the influence of the air / fuel ratio on the levels of emissions of pollutants discussed in details in *(19)*. This kind of variation in different emission types was mentioned in *(4)*. These authors also discussed the effect of engine loads and stoichiometric (enough air to completely burn the available fuel) engine conditions on this emission behavior.

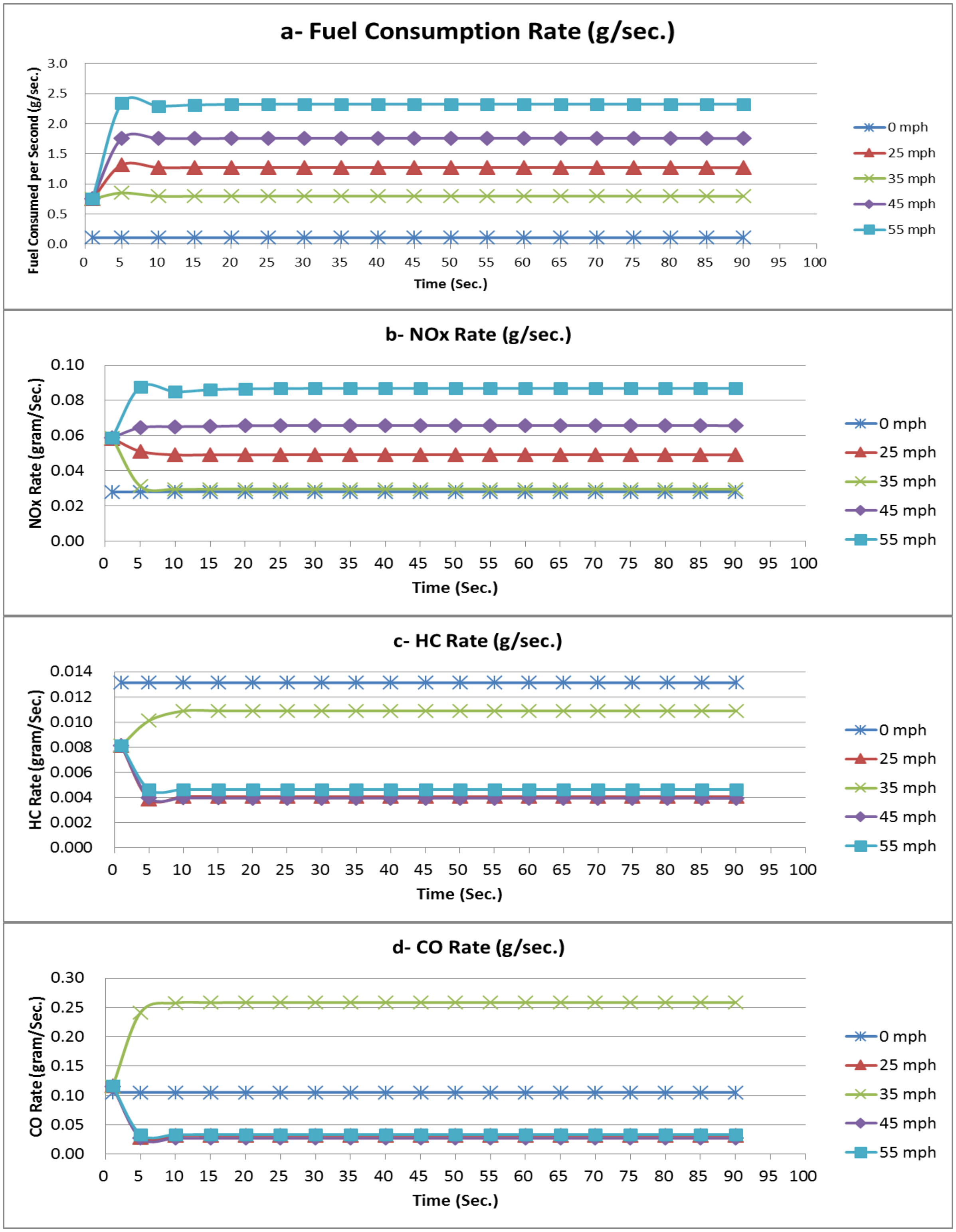


FIGURE 3 Fuel consumption and emission rates for the cases of idling and cruising.

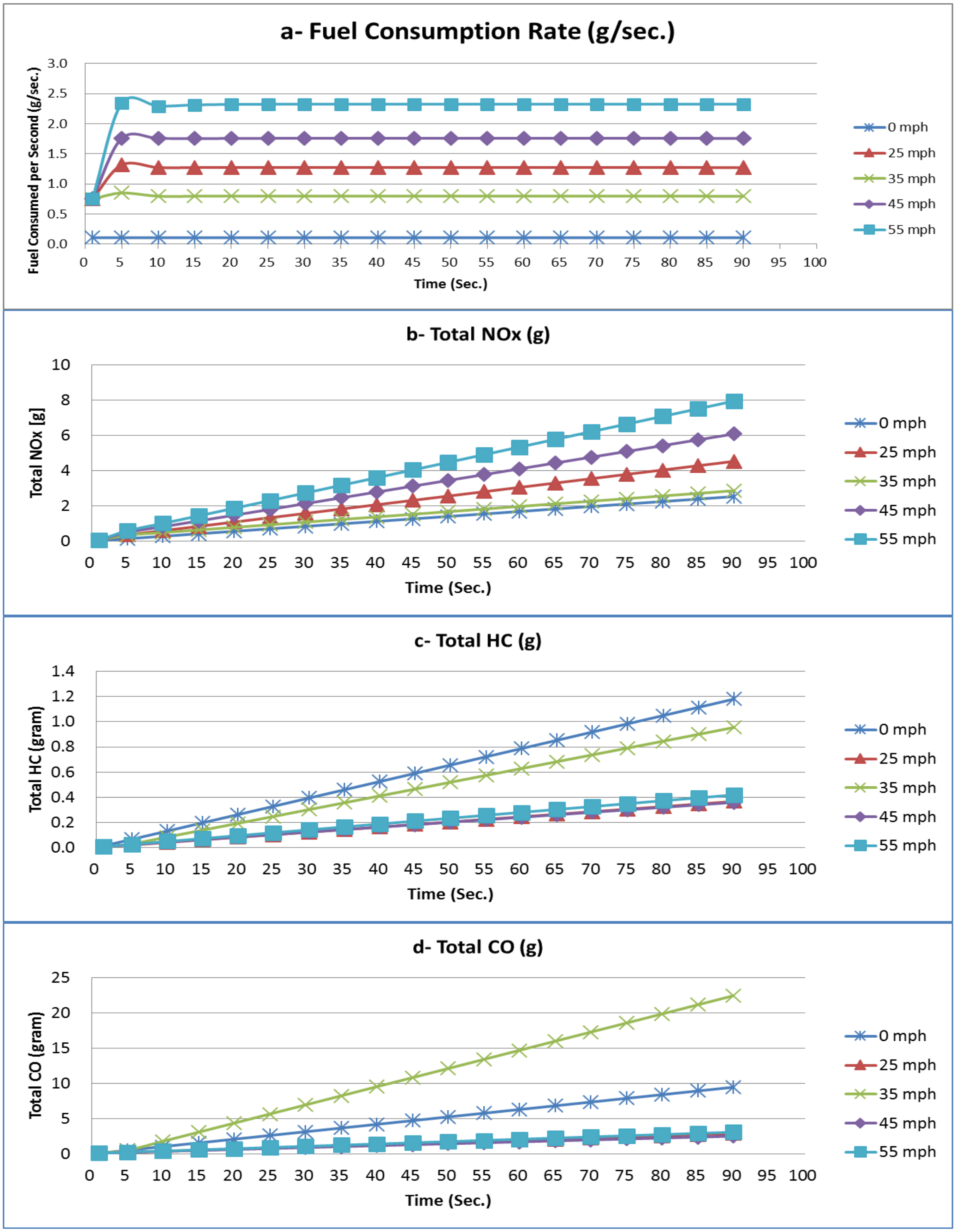


FIGURE 4 Total fuel consumption and emissions for the cases of idling and cruising.

3.3 Case Three: The Impact of Accelerating from a Stopped Position, Acceleration Behavior, and Target Operating Speeds:

Case three represents a vehicle stopped at an intersection approach and accelerating back to its target and desired driving speed. In this analysis, four different target speeds were modeled using the GT-Suite: 25 mph, 35 mph, 45 mph, and 55 mph (**FIGURE 2**-C). The acceleration happened from zero mph to each one of these target speeds using three different acceleration values. These acceleration values are mild acceleration (4.7 ft. /sec.^{2}), normal acceleration (7.1 ft. /sec.^{2}), and aggressive acceleration (11.8 ft. /sec.^{2}). These four target speeds with the three acceleration values for each one of these target speeds formed a total of 12 different subcases. These 12 subcases show the effect of different acceleration values and driver aggressiveness on fuel consumption and emissions.

Because of the different acceleration values, the modeled engine reached each target speed over different times and distances. For example, it would take the modeled engine in GT-Suite a time of 18.3 seconds to go from a speed of zero mph to a target speed of 55 mph in the mild acceleration mode (4.7 ft. /sec.^{2}), while it would take the same engine a time of 13.68 seconds to reach the same target speed of 55 mph from a zero mph starting speed in the aggressive acceleration mode (11.8 ft. /sec.^{2}). To make a fair comparison between the 12 different cases, all of these 12 different cases were modeled in the GT-Suite to cover a same distance of 720 ft. If the vehicle reached the target speed before the 720 ft., the vehicle would simply cruise on the target speed till it covers the 720 ft.

TABLE 1 summarizes the total amounts of fuel consumption and emissions for the different target and acceleration cases over a distance of 720 ft. To show the data from a different perspective,

FIGURE 5 shows the fuel consumption and emission rates and total amounts for the case of accelerating from a zero mph using three different acceleration values (mild, normal, and aggressive).

TABLE 1 Fuel Consumption and Emissions Rates for the Case of Accelerating From Zero mph to Different Target Speeds Using Different Acceleration Values Over a Distance of 720 ft.

		Fuel Cons. Rate (g./sec.)	**NOx Rate (g./sec.)**	**HC Rate (g./sec.)**	**CO Rate (g./sec.)**
	4.7 ft. / sec.^{2}	0.881	0.068	0.0069	0.064
	7.1 ft. / sec.^{2}	0.961	0.100	0.0068	0.064
	11.8 ft. / sec.^{2}	1.002	0.099	0.0070	0.091
	4.7 ft. / sec.^{2}	0.967	0.079	0.0078	0.106
	7.1 ft. / sec.^{2}	1.039	0.105	0.0079	0.114
	11.8 ft. / sec.^{2}	1.103	0.099	0.0080	0.136
	4.7 ft. / sec.^{2}	1.322	0.104	0.0062	0.056
	7.1 ft. / sec.^{2}	1.473	0.128	0.0061	0.056
	11.8 ft. / sec.^{2}	1.541	0.126	0.0063	0.080
	4.7 ft. / sec.^{2}	1.599	0.111	0.0059	0.053
	7.1 ft. / sec.^{2}	1.773	0.131	0.0058	0.053
	1.8 ft. / sec.^{2}	1.835	0.129	0.0059	0.076

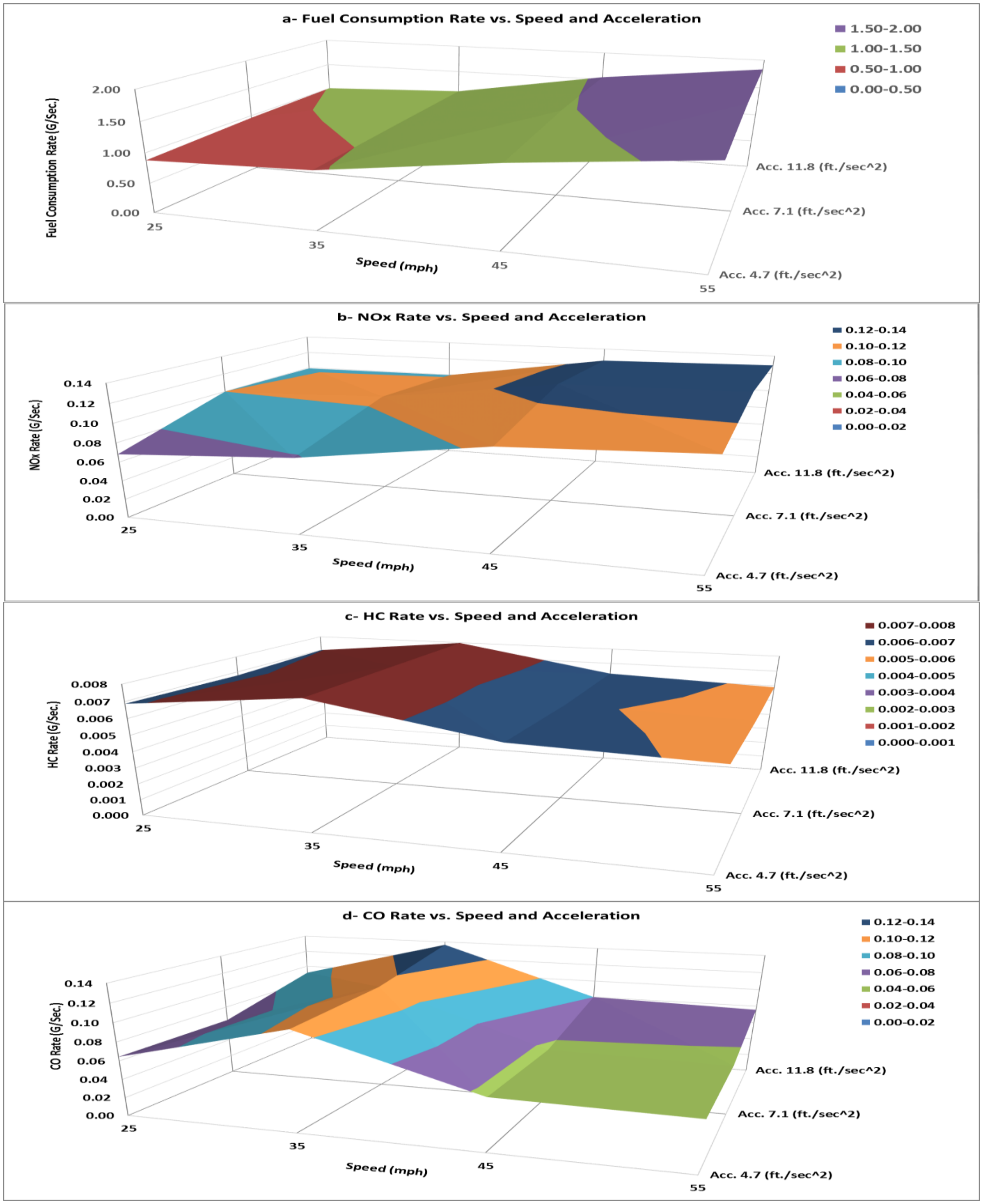


FIGURE 5 Fuel consumption and emission rates for the cases of accelerating from zero to 55 mph using different acceleration values (gram/sec.).

TABLE 1 and

FIGURE 5 show that:

- **Regarding the Fuel Consumption:** mild acceleration behavior causes lower fuel consumption rates (gram / second) compared to the normal acceleration case. The same result is valid for normal acceleration that causes less fuel consumption rates compared to the aggressive acceleration. The average fuel consumption rate increase in the case of normal acceleration is 9.69% compared to the mild acceleration case, while the average fuel consumption rate increase in the case of aggressive acceleration is 14.76% compared to the mild acceleration case.

On the other hand, mild acceleration is typically causing higher amounts of accumulated fuel consumption (grams) until the point of reaching a target speed compared to the other two cases of normal and aggressive acceleration. This occurs because, in the case of mild acceleration, the vehicle will typically take more acceleration time to get to the target speed, causing an increase in the accumulated fuel consumption.

- **Regarding the NO_x emissions:** The relation between the NO_x emission rates and fuel consumption rates is nonlinear. NO_x emission rates increase in the normal acceleration case (7.1 ft. /s^2) compared to the mild acceleration case (4.7 ft. /s^2) with a percentage of 23.44%. The aggressive acceleration case has a 21.6% higher NO_x rate compared to the mild acceleration case, but this increase is lower than the normal acceleration case. This behavior is consistent with other studies *(19)*, *(4)*, and *(18)* and can be attributed to two reasons. First, NO_x emissions are very high at the stoichiometric engine conditions as opposed to high engine loads. Second, in the case of mild acceleration, the vehicle takes a longer time to reach the desired target speeds compared to the mild and aggressive accelerations, causing the emission rates to be higher. When comparing the effect of cruising speeds and acceleration levels, it should be noted that cruising speeds have much higher effects on the NO_x emission rates compared to the different acceleration levels.

- **Regarding the HC and CO emissions:** HC and CO emission rates revealed similar behavior to the fuel consumption rates. The more aggressive the acceleration is, the more the engine operates in a higher fuel to air ratio mode, which is required to prevent engine knocking, thus bypassing the catalytic converter, and so the higher HC and CO emission rates. In the case of CO, the average CO emission in the case of normal acceleration is slightly higher than the mild acceleration mode, but the CO emission rate in the case of aggressive acceleration is 38.77% higher than the CO emission rates in the case of mild acceleration. This general behavior is consistent with other studies *(4)* and *(18)*.

This part of the study revealed higher level of acceleration resulting in higher fuel consumption and emission rates because of the high and rich fuel/air ration needed for aggressive accelerations to prevent engine knocking, thus bypassing the catalytic converter and increasing vehicle emissions. Fuel consumption rates increased by increasing theacceleration rate. NO_x emissions increased in the mild to normal acceleration range and decreased in the aggressive acceleration range. HC and CO emissions increased by increasing the acceleration rates.

3.5 Case Four: Accelerating From Non-Zero Speeds:

TABLE 2 Total Fuel Consumption and Emissions for the Case of Accelerating from Non-Zero Values

		Fuel (g)	NOx (g)	HC (g)	CO (g)
	5-25 mph	28.294	1.841	0.083	0.711
	10-25 mph	27.575	1.56	0.08	0.701
	15-25 mph	26.38	1.284	0.077	0.656
	20-25 mph	24.841	1.026	0.074	0.576
	5-35 mph	24.69	1.816	0.115	2.405
	10-35 mph	23.921	1.58	0.113	2.398
	15-35 mph	22.289	1.289	0.113	2.442
	20-35 mph	20.724	1.077	0.112	2.449
	5-45 mph	36.784	2.66	0.052	0.398
	10-45 mph	35.821	2.421	0.052	0.436
	15-45 mph	34.496	2.15	0.048	0.385
	20-45 mph	33.306	1.942	0.045	0.316
	5-55 mph	46.301	2.901	0.045	0.351
	10-55 mph	45.41	2.693	0.045	0.396
	15-55 mph	43.958	2.418	0.04	0.332

	20-55 mph	42.671	2.197	0.037	0.268

summarizes the total amounts of fuel consumption and emissions for accelerating from non-zero values. Although the fuel consumption and environmental cost of vehicles delayed at the intersection approach because of a queue are lower than that for stopped vehicles, the data reveals these vehicles still constitute a significant portion of the fuel consumed and pollutants emitted as a result of the corridor operations. In addition, these costs increase when the operating speed of the corridor increases.

TABLE 2 Total Fuel Consumption and Emissions for the Case of Accelerating from Non-Zero Values

		Fuel (g)	NO_x (g)	HC (g)	CO (g)
	5-25 mph	28.294	1.841	0.083	0.711
	10-25 mph	27.575	1.56	0.08	0.701
	15-25 mph	26.38	1.284	0.077	0.656
	20-25 mph	24.841	1.026	0.074	0.576
	5-35 mph	24.69	1.816	0.115	2.405
	10-35 mph	23.921	1.58	0.113	2.398
	15-35 mph	22.289	1.289	0.113	2.442
	20-35 mph	20.724	1.077	0.112	2.449
	5-45 mph	36.784	2.66	0.052	0.398
	10-45 mph	35.821	2.421	0.052	0.436
	15-45 mph	34.496	2.15	0.048	0.385
	20-45 mph	33.306	1.942	0.045	0.316
	5-55 mph	46.301	2.901	0.045	0.351
	10-55 mph	45.41	2.693	0.045	0.396
	15-55 mph	43.958	2.418	0.04	0.332
	20-55 mph	42.671	2.197	0.037	0.268

3.6 The Fuel Consumption and Emissions Cost of Stopping:

The data presented in

TABLE 1, **TABLE 3**, **FIGURE 4**, and

FIGURE 5 document the fuel consumption and environmental cost of vehicles stopping at signalized intersection approaches. For example, a vehicle accelerating back from a stopped position to a speed of 45 mph using a normal acceleration will consume 38.59 grams of fuel. A non-stopped vehicle cruising through the intersection approach for the same distance would consume 20.27 grams of fuel. This demonstrates that the cost of a single stop for an average 4-cylinder vehicle is approximately 18.32 grams. Such quantitative-based comparison could be used to provide transportation professionals with a more accurate fuel consumption and environmental cost of stops and delay to assist them in making decisions about optimizing different intersections and corridors.

TABLE 3-A shows that the cost of stopping can be calculated at each driving speed for vehicles running for the same distance (720 ft. in this example). This could be performed by making a comparison between vehicles cruising at 720 ft., and other vehicles starting from zero mph and accelerating normally (7.1 ft/s^2) to different driving speeds (25, 35, 45, and 55 mph). A similar table, **TABLE 3**-B, is provided for the case of accelerating normally from non-zero values (for example 10 mph).

TABLE 3 shows the negative effects of stopping at signalized intersections could be easily seen especially at higher driving speeds. The table also shows the cost of stopping from a speed of 55 mph is 26.28 grams of fuel compared to 4.82 grams in the case of 25 mph. Previous tables and graphs also show that the fuel consumption cost in the case of 25 mph (4.82 g) is equivalent to idling at a signalized intersection for a period of 46 seconds. The 4.8 grams of fuel could be obtained by going vertically up at the 46 seconds location on the horizontal axis.

Several conclusions can be drawn from the presented data. First, fuel consumption and environmental cost of stops are highly dependent on the corridor operating speeds and increases as the speed increases. Second, drivers' acceleration patterns significantly affect the fuel consumption and environmental cost of stops. Aggressive driving with high acceleration rates yields a much higher fuel consumption and environmental costs. The numbers shown in previous tables and figures could be used in public awareness campaigns to show how aggressive driving practices can affect significantly the fuel consumption and environmental cost.

TABLE 3 Cost of Stopping (Units In Grams)

3-A- Accelerating From Zero mph

	0-25 mph	**25 mph cruise**	**Cost**	**0-35 mph**	**35 mph cruise**	**Cost**	**0-45 mph**	**45 mph cruise**	**Cost**	**0-55 mph**	**55 mph cruise**	**Cost**
Fuel	30.72	25.89	4.82	26.28	14.03	12.25	38.59	20.27	18.31	47.94	21.66	26.28
NOx	2.29	1.09	1.20	2.27	0.61	1.66	3.11	0.89	2.22	3.35	0.93	2.42
HC	0.09	0.08	0.01	0.13	0.13	0.00	0.06	0.05	0.01	0.06	0.04	0.01
CO	0.88	0.69	0.19	2.73	2.84	-0.11	0.61	0.40	0.21	0.57	0.39	0.18

3-B- Accelerating From Non-Zero Speed

	10-25 mph	**25 mph cruise**	**Cost**	**10-35 mph**	**35 mph cruise**	**Cost**	**10-45 mph**	**45 mph cruise**	**Cost**	**10-55 mph**	**55 mph cruise**	**Cost**
Fuel	27.575	25.89	1.68	23.921	14.03	9.89	35.821	20.27	15.55	45.41	21.66	23.75
NOx	1.56	1.09	0.47	1.58	0.61	0.97	2.421	0.89	1.53	2.693	0.93	1.76
HC	0.08	0.08	0.00	0.113	0.13	-0.01	0.052	0.05	0.00	0.045	0.04	0.00
CO	0.701	0.69	0.01	2.398	2.84	-0.44	0.436	0.40	0.04	0.396	0.39	0.01

3.7 Conclusion and Recommendations

While corridor traffic in small and medium size cities does not experience the high levels of congestion typically present in large urban areas, it generates a considerable amount of emissions and vehicle pollutants that has a negative impact on the environment. The main objective of this work is to quantify fuel consumptions and emissions in more depth for vehicles operating at signalized intersection approaches. The results presented in this paper show that the fuel consumption and environmental cost of stops are highly dependent on the corridor operating speeds and increases as the speed increases. Another factor that impact the fuel consumption and environmental cost of the stops is the drivers' acceleration patterns. Aggressive driving with high acceleration rates, yields much higher fuel consumption cost.

As a summary of this part, it could be concluded that higher level of acceleration resulted in higher fuel consumption and emission rates. This is because of the high and rich fuel/air ration needed for this kind of aggressive accelerations which is required to prevent engine knocking, thus bypassing the catalytic converter and increasing vehicle emissions. Fuel consumption rates increased by increasing the acceleration rate. NO_x emissions increased in the mild to normal acceleration range and decreased in the aggressive acceleration range. HC and CO emissions increased by increasing the acceleration rates. Public awareness campaigns about the high cost of aggressive driving practices can contribute significantly to the reduction of corridor fuel consumption and environmental cost.

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