

Vehicle Aggregation Impacts on Fuel Consumption and Emission Estimates

By

R. Sivanandan

Associate Professor
Department of Civil Engineering
Indian Institute of Technology – Madras
Chennai 600 036
India
Phone: 011-91-44-22578301
E-mail: siva@civil.iitm.ernet.in

Hesham Rakha

(Corresponding Author)
Associate Professor, Charles Via Department of Civil and Environmental Engineering
Leader, Transportation Systems and Operations Group
Virginia Tech Transportation Institute
3500 Transportation Research Plaza (0536)
Blacksburg, VA 24061
Phone: (540) 231-1505
Fax: (540) 231-1555
E-mail: rakha@vtti.vt.edu

November 14, 2003

Submitted for consideration for presentation (and later publication in TRR)
at the TRB Annual Meeting, January 2004

Word Count:

Text: 5,667
Figures and Tables: 8 (2000 words)
Total: 7,667 words

ABSTRACT

Typically the evaluation of transportation improvement projects necessitates the evaluation of the environmental impacts of these projects. However, the environmental evaluation is typically difficult, particularly, in the pre-implementation stage and in the presence of various types of vehicles with differing fuel consumption and emission characteristics.

Current state-of-the-art and state-of-the-practice energy and environmental models consider an average composite vehicle in evaluating the energy and environmental impacts of transportation projects. However, the literature does not investigate whether the use of an average composite vehicle as opposed to explicitly modeling the vehicles that constitute this average vehicle could alter the conclusions of transportation environmental studies. The paper attempts to address this concern using the INTEGRATION microscopic traffic simulation and assignment model on an arterial corridor. Three types of analyses are considered. First, the vehicle population is considered to be entirely composed of a single vehicle model. Specifically, eight different model types are considered in the analysis ranging from small compact cars to light duty trucks. Second, the analysis considers a population composed of 12.5 percent of each of the vehicle models. Finally, the study considers the use of an average composite vehicle instead of modeling the individual vehicles that constitute the composite vehicle. Several scenarios of vehicle speeds and traffic controls are tested as part of the study.

The primary conclusion of the study is that although there are significant differences in fuel consumption and emission estimates depending on the vehicle type considered, the modeling of an average composite vehicle tends to produce conclusions that are consistent with the explicit modeling of the various vehicle types that constitute the vehicle fleet. However, in some rare instances the modeling of an average composite vehicle does not produce identical conclusions as predicted by explicitly modeling the various vehicles that constitute the average composite vehicle. The findings are believed to be useful in developing modeling strategies for environmental evaluation studies.

Key words: Transportation energy modeling, transportation environmental modeling, composite vehicle, INTEGRATION, VT-Micro

INTRODUCTION

As part of the evaluation stage of transportation improvement projects, the implementing agency is interested in assessing the potential benefits that will accrue from such an implementation. Oftentimes, Measures of Effectiveness (MOEs) on network-wide improvements, such as reductions in total system travel time and delays, and average speeds are accepted as reasonably good indicators of potential benefits of the proposed project. However, these parameters do not capture the environmental impacts of such projects. With increasing environmental concerns and thrust towards fuel conservation, environmental issues are of major concern. Particularly, with the introduction of Intelligent Transportation Systems (ITS) technologies in the past decade, evaluation of emissions and fuel consumption has attained greater significance and importance. In several instances, justification of the use of ITS technologies could hinge on the environmental gains that these technologies could bring about.

Often, simulation of vehicular traffic is used to assess the fuel consumption and emissions. In doing so, it is essential to gather information about the various types of vehicles that are to be simulated. This will enable a more accurate assessment of the fuel consumption and emission estimates. However, such information is hard to obtain. The current state-of-the-art energy and emission models utilize an average composite vehicle for quantifying the energy and environmental impacts of transportation projects. Unfortunately, it is not clear at this point, what impact vehicle characteristics and vehicle aggregation has on the results and conclusions of such studies.

Objectives of Research

The objective of this research effort is to systematically study the impact of vehicle characteristics and vehicle aggregation on the conclusions of energy and environmental studies. The approach that is utilized to address this objective involves usage of the INTEGRATION microscopic traffic simulation and assignment model (1, 2) for the modeling of a number of scenarios that are typical of urban areas. While these scenarios are not comprehensive in nature, they do provide some insight into the potential impacts of vehicle characteristics and vehicle aggregation on the outcomes of transportation environmental studies.

Significance of Research and Paper Layout

Numerous variables influence vehicle energy and emission rates. These variables can be classified into six broad categories, as follows: travel-related, weather-related, vehicle-related, roadway-related, traffic-related, and driver-related factors. The travel-related factors account for the distance and number of trips traveled within an analysis period while the weather-related factors account for temperature, humidity, and wind effects. Vehicle-related factors account for numerous variables including the engine size, the condition of the engine, whether the vehicle is equipped with a catalytic converter, whether the vehicle's air conditioning is functioning, and the soak time of the engine. The roadway-related factors account for the roadway grade and surface roughness, while the traffic-related factors account for vehicle-to-vehicle and vehicle-to-control interaction. Finally, the driver-related factors account for differences in driver behavior and aggressiveness.

The state-of-the-art emission models such as MOBILE6 developed by the US Environmental Protection Agency (EPA) and EMFAC7F developed by the California Air Resources Board (CARB) attempt to account for travel-related, weather-related, and vehicle-related factors on vehicle emissions using an aggregate average vehicle. Unfortunately, it is not clear at this point what impact these vehicle-related factors have on the outcomes of environmental studies. Furthermore, it is not clear what impact vehicle aggregation has on the outcome of transportation studies.

Consequently, this study makes two significant contributions. First, it investigates the impact of different vehicle characteristics on the conclusions of environmental studies using several simple scenarios. Second, it investigates the impact of aggregating constituent vehicles into an average composite vehicle on the outcome of environmental studies.

The paper is structured in the following manner. After providing a basic background in the subject area, the methodology adopted in this study is described. This is followed by a description of the test scenarios and model runs. The results are then presented and analyzed followed by the study conclusions.

BACKGROUND

This section begins by describing the traditional state-of-practice methods for quantifying the environmental impacts of transportation projects. Subsequently, the emerging microscopic energy and emission models that were developed at Virginia Tech are described, since these models form the basis for this study.

MOBILE and EMPAC Models

Two emission models that are commonly utilized in the United States are the Environmental Protection Agency's (EPA's) MOBILE5 model and the California Air Resources Board's (CARB's) EMFAC model. Different versions of the MOBILE5 model exist, including MOBILE5a, MOBILE5b, and MOBILE6. These models have been authorized by the EPA to conduct conformity analyses. The EMFAC model is currently utilized in the state of California, while EPA is requiring the use of MOBILE6 in all states in the US by the beginning of 2004. Both models produce activity specific emission rates that are a function of vehicle type and age, average speed, temperature, altitude, vehicle loads, air conditioning usage, and vehicle operating mode. These emission rates are multiplied by vehicle activities such as vehicle miles-traveled, number of trips and vehicle-hours traveled in order to estimate total emission levels. The MOBILE6 model estimates three pollutants: hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x), while the EMFAC model produces composite emission factors for four pollutants, including total organic gases, carbon monoxide, oxides of nitrogen, and particulate matter (3).

Current estimates of emission rates produced by the MOBILE6 and EMFAC models are expressed as functions of average speeds and are based on vehicle testing on a number of driving cycles (14 drive cycles in the case of the MOBILE6 model). In the case of the MOBILE6 model baseline emission rates are derived for the 14 drive cycles. Facility-specific baseline emission rates for a vehicle class are derived from the various drive cycles and correction factors are utilized to account for differences in facility-specific average speeds. In the EMFAC model, the baseline emission rate is derived from the stabilized phase of the FTP cycle with an average operating speed of 25.6 km/h (16 mph) (4).

Emission rates at other average speeds are multiplied by the appropriate Speed Correction Factor (SCF) associated with a vehicle class and operating speed. The SCFs are estimated using the average cycle speed as an independent variable and the emission rates as a dependent variable. Therefore, speed-corrected emission rates used in macroscopic emission models are highly dependant on the average cycle speed (3).

The use of SCFs for estimating vehicle emissions suffers from a number of limitations, as discussed in the following sections. First, a limited set of driving cycles, which insufficiently represent specific traffic flow conditions, are used to estimate emission rates in current models. Many of the driving cycles are out of date (the FTP is more than 20 years old), and, thus, may not represent current real world driving conditions. Analysis of three cycles, which include the FTP cycle and two recently developed cycles (Freeway 6 and Arterial 1) with the same average speed, found that the Federal Test Procedure (FTP) cycle underestimated driving conditions at higher speeds and acceleration, both of which are known to be sources of high emissions (3).

Second, current emission models predict emission rates on a single traffic-related variable, namely the average speed. Average trip speeds are not equivalent to link-specific speeds for portions of vehicle trips. This method using average speeds

cannot represent the distribution of speeds and accelerations of a trip, which vary by type of facility and level of congestion. For example, existing emission models cannot distinguish between a highly congested freeway and normal density arterial with the same average speed, though each trip involves a different distribution of vehicle speed and acceleration levels causing distinct emission differences (3).

The Virginia Tech Microscopic Energy and Emission Models

The Virginia Tech Microscopic energy and emission model (VT-Micro) was developed from experimentation with numerous polynomial combinations of speed and acceleration levels (5, 6, and 7). Specifically, linear, quadratic, cubic, and quartic terms of speed and acceleration were tested using chassis dynamometer data collected at the Oak Ridge National Laboratory (ORNL), at the Automotive Testing Laboratories, Inc. (ATL), in Ohio, and at EPA's National Vehicle and Fuels Emission Laboratory (NVREL), in Ann Arbor. The final regression model included a combination of linear, quadratic, and cubic speed and acceleration terms because it provided the least number of terms with a relatively good fit to the original data (R^2 in excess of 0.92 for all MOEs). It is sufficient to note at this point that the final structure of the model, which is summarized in Equation 1, involved a logarithmic transformation of a dual-regime third order polynomial.

As is the case with any mathematical model, the proposed models are applicable for a specified domain of application. First, the models are developed to estimate vehicle fuel consumption and emission rates for light duty vehicles and trucks. Second, the models estimate vehicle emissions for hot stabilized conditions and do not consider the effect of vehicle start effects. It should be noted, however, that second-by-second data obtained from the EPA have proven valuable in determining the differences between hot-running and cold-start engines and a model has been developed to add this contribution as an external additive function to the models presented here. Third, the models are confined to speed and acceleration levels within the envelope of the ORNL data.

The third limitation inherent in model application in model limitation directly relates to the difficulty associated with models in general to extrapolate response values beyond the boundaries used in the model calibration procedure. While most vehicles can travel faster than 121 km/h (upper limit of the testing boundary), it is impossible to establish a reliable forecasting pattern for energy and emission rates at high speeds due to the heavy nonlinear nature of the response curves. It has been observed from the US06 cycle that some speed and acceleration profiles exceed the speed and acceleration boundary (13 out of 596 seconds). However, in these cases, it is recommended to use boundary speed and acceleration levels in order to ensure realistic vehicle MOE estimates. Furthermore, it should be noted that these models have been successfully applied to Global Positioning System (GPS) speed measurements after applying robust smoothing techniques in order to ensure feasible speed measurements (7).

$$\ln(MOE_e) = \begin{cases} \sum_{i=0}^3 \sum_{j=0}^3 (L_{i,j}^e \times u^i \times a^j) & \text{for } a \geq 0 \\ \sum_{i=0}^3 \sum_{j=0}^3 (M_{i,j}^e \times u^i \times a^j) & \text{for } a < 0 \end{cases} \quad [1]$$

Where:

MOE_e = instantaneous fuel consumption or emission rate (l/s or mg/s),

- $L_{i,j}^e$ = Model regression coefficient for MOE “e” at speed power “i” and acceleration power “j”,
 $M_{i,j}^e$ = Model regression coefficient for MOE “e” at speed power “i” and acceleration power “j”,
 u = Instantaneous vehicle speed (km/h), and
 a = Instantaneous vehicle acceleration (m/s²).

The ORNL data that were utilized to develop the fuel consumption and emission models that are presented in this paper were measured in a laboratory on a chassis dynamometer within the vehicle’s feasible vehicle speed and acceleration envelope. Data sets were generated that included vehicle energy consumption and emission rates as a function of the vehicle’s instantaneous speed and acceleration levels. Several measurements were made in order to obtain an average fuel consumption and emission rate. The emission data that were gathered included hydrocarbon (HC), oxides of nitrogen (NO_x), and carbon monoxide (CO) emission rates.

The eight normal emitting vehicles included five light-duty automobiles and three light duty trucks, as summarized in Table 2. These vehicles were selected in order to produce an average vehicle that was consistent with average vehicle sales in terms of engine displacement, vehicle curb weight, and vehicle type. Specifically, the average engine size was 3.3 liters, the average number of cylinders was 5.8, and the average curb weight was 1497 kg (3300 lbs). Industry reports at that time showed that the average sales-weighted domestic engine size in 1995 was 3.5 liters, with an average of 5.8 cylinders (6).

The data collected at ORNL contained between 1,300 to 1,600 individual measurements for each vehicle and Measure of Effectiveness (MOE) combination depending on the envelope of operation of the vehicle. Typically, vehicle acceleration values ranged from – 1.5 to 3.7 m/s² at increments of 0.3 m/s² (-5 to 12 ft/s² at 1 ft/s² increments). Vehicle speeds varied from 0 to 33.5 m/s (0 to 121 km/h or 0 to 110 ft/s) at increments of 0.3 m/s. The data demonstrated large nonlinear behavior in all MOEs as a function of the vehicle speed and acceleration. Specifically, ‘peaks’ and ‘valleys’ were prevalent as a result of gear shifts under various driving conditions. In addition, it was evident that as acceleration and speed increased the MOEs generally tended to increase. Furthermore, it was noted that the gradient of the MOEs in the negative acceleration regime (-1.5 to 0 m/s²) was generally smaller than that in the positive acceleration regime (0 to 3.7 m/s²).

In addition to gathering data on the individual eight vehicles, data for an average composite vehicle were constructed by averaging the raw data observations over the eight test vehicles. It is interesting to note that the ORNL data represents a unique vehicle performance envelope. For example, low weight-to-power ratio vehicles have better acceleration characteristics at high speeds than their high weight-to-power ratio counterparts. Consequently, the average composite vehicle would be weighted more towards the low weight-to-power vehicles at the high engine loads.

Using the ORNL data fuel consumption and emission models were derived for the individual vehicles and for the average composite vehicle. These models were incorporated within the INTEGRATION traffic simulation and assignment software and applied as part of this study.

STUDY METHODOLOGY

Overview

The crux of the methodology relies on the use of simulation as a tool to evaluate the influence of adopting composite vehicle (vis-à-vis various types of vehicles) on fuel consumption and emission estimates for a road network. The premise here is that if the use of such composite vehicles is analogous to the explicit modeling of a mixture of vehicles, then the environmental modeling process may be significantly simplified. The essence here is to simulate the vehicles through a network and analyze the fuel consumption and emissions of the vehicles obtained through the model. An overview of the adopted methodology is presented in Figure 1. The first step was to create a test network. To begin with, a hypothetical network was developed for this purpose. It is a 4-km linear network representing an urban arterial with two zones and three intersection links. Various test scenarios to depict different types of vehicles, variations in speeds of vehicles, and traffic control at intersections, were developed to apply the study methodology. Simulation runs using the INTEGRATION model were made for the various test scenarios and the fuel consumption and emission estimates from the model were analyzed and compared.

Simulation Tool

For this study, the INTEGRATION microscopic traffic simulation model (1, 2) was selected as the tool for a number of reasons. The primary reason for this was that this model uses state-of-the-art vehicle fuel consumption and emission models in conjunction with the explicit modeling of vehicle dynamics, as is described in detail in the literature (9). Since the focus of this paper is on fuel consumption and emissions, this model was preferred. Also, the model, which was conceived during the mid-1980's as an integrated simulation and traffic assignment model (10-14), has been effectively used by a number of private engineering firms and public transportation agencies for the evaluation of various transportation projects (5, 15, 16, 17). Consequently, the software is accepted by a wide audience of transportation professionals. In addition, the fact that the INTEGRATION software explicitly models dynamic traffic assignment as opposed to assigning turn probabilities at nodes, which is what is commonly used in other microscopic simulation software including CORSIM and VISSIM, the model can provide origin-destination specific output. This key advantage evolves from the fact that the INTEGRATION software, unlike most microscopic software, tracks individual vehicles from their point of origin to their final point of departure. These unique features of the INTEGRATION software are briefly discussed in the following paragraphs.

The INTEGRATION model captures the movement of vehicles from their point of origin to their final destination at a 1/10 of a second level of resolution. This microscopic approach permits the detailed analysis of many traffic phenomena, such as shock waves, gap acceptance, and weaving behavior. It also permits considerable flexibility in representing spatial variations in traffic conditions. The dynamic approach adopted by the model further allows it to consider virtually continuous time-varying demands, routings, link capacities, and traffic controls without the need to pre-define an explicit common time-slice duration. This implies that the model is not restricted to hold departure rates, signal timings, incident severities, and even traffic routings at a constant setting for any particular period of time. The INTEGRATION model can be used not only to estimate stops and delays, but also to estimate vehicle fuel consumption and emissions within a simulated network (8, 9, 18). Embedded in the model are routines

that compute the fuel consumption and emissions of hydrocarbon (HC), carbon monoxide (CO) and oxides of nitrogen (NO_x) of each simulated vehicles on a second-by-second basis based on the vehicle's instantaneous speed and acceleration levels. As was mentioned earlier, the estimates that are provided in the paper are based on models developed utilizing the data collected by Oak Ridge National Laboratories (ORNL) (19).

Test Network

The test network used in this study was a hypothetical network. It was designed to represent an urban arterial linear corridor consisting of four equal sections of one mile each, with three intersection nodes, as shown in Figure 2. For the research presented in this paper, the zones at the end of the linear section (1-2) were taken as the origin-destination (O-D) pair of interest. In other words, only vehicular trips originating from zone 1 destined for zone 2 within the hypothetical network were considered. As for traffic control at the intersections at cross roads, three different controls were tested – no control, STOP signs, and signals. The network was coded consistent with INTEGRATION model requirements. Though only a linear corridor was tested, the methodology is extendable to networks of any size and with traffic controls of any level. Consequently, it is recommended that further testing be conducted on larger networks with significant traffic demands.

Test Scenarios

In order to accomplish the objectives of this research effort, various test scenarios were conceived. They were designed to mimic various real-life traffic situations on a network. These included varying speeds, various types of vehicles, single and multiple vehicles, and different types of traffic control. Table 1 summarizes the various test scenarios. The speeds used for the tests ranged from 25 km/h to 100 km/h, in increments of 25 km/h. The traffic controls at intersection nodes included no control, STOP signs, and traffic signals.

The various vehicle types included in the test scenarios are summarized in Table 2. These vehicle types are consistent with those employed by the INTEGRATION model, using the fuel consumption and emission data collected by West et al. (1997). A total of eight light duty vehicles of different weights and engine sizes were utilized. Specifically, the vehicle types that were used in this study were: the ORNL Composite Light Duty Vehicle (LDV) (average of 5 LDVs and 3 Light Duty Trucks (LDTs)) and the individual vehicles that constitute the composite vehicle. Each run was executed five times using a different random number seed. The results that are presented represent the mean of the five runs.

Various combinations of these variables were employed in the test runs to introduce realism into the evaluation of their influence on fuel consumption and emissions. The description of model runs for the test scenarios and their results are provided below. They are categorized into three groups – uniform speed, STOP control and signal control scenarios. The descriptions that follow are structured around these three groups.

MODEL RUNS AND ANALYSIS OF RESULTS

Uniform Speed Scenario

To begin with, the case of uniform or constant speed was taken up. Here, a single vehicle was simulated through the linear network, originating at zone 1 and destined to 2 (Figure 2). The three intersections were assumed to have no traffic control (in other words, the vehicle could pass through these intersections without any interruptions or delays). The four different speeds mentioned earlier were considered for each of the vehicle types. Appropriate input files were prepared for each case and the INTEGRATION model was run. The output file which gives out second-by-second statistics on vehicle fuel consumption and emissions (HC, CO and NO_x), among other parameters, was analyzed. The total fuel consumed and emissions produced for the entire trip were computed for each of the cases. The emissions for a sample of vehicles are plotted against speed and illustrated in Figure 3. The figure demonstrates a bowl shaped fuel consumption relationship similar to what is reported in the literature for the majority of vehicles including the average composite vehicle. However, the Cutlass Supreme exhibits a behavior that is different from the other vehicles. Similar inconsistencies for the Cutlass Supreme are observed for the HC and CO emissions. It is speculated that the Cutlass Supreme could have had some malfunction and thus would be categorized as a high emitter. In general, the composite vehicle exhibits an average trend when compared to the individual vehicles.

In order to determine whether the means of fuel consumption and emissions of composite vehicle were different from those of individual vehicles types, paired t-tests were conducted at the 5 percent level of significance. The results indicate that in the case of fuel consumption, the means of vehicle types 5 and 8 were statistically different from that of the composite vehicle. In the case of HC, only vehicle 5 showed a difference. Considering CO, all the vehicle types (2, 4, 5, 7, 8) produced emissions that were statistically different from those of the composite vehicle. On the contrary, for NO_x, the means for all the vehicles were not statistically different from that of the composite vehicle. Thus, in all, out of 20 comparisons of means, 12 cases showed no statistical differences. It must, however, be noted that the test case results are based on a single vehicle as a first step in the analysis.

STOP Sign Scenario

This scenario was designed to mimic STOP signs at all the three intersections, all other parameters remaining the same. A single vehicle was again simulated through the linear network, and the output analyzed for fuel consumption and emissions. Figure 4 shows the variations in fuel consumption and emissions with speed for the various vehicles, including the composite vehicle. A cursory look at this figure in comparison to Figure 3 clearly shows that the values of all the parameters (fuel consumption, HC, CO and NO_x) are generally higher for the STOP sign scenario. Again, the trends for the Oldsmobile Cutlass Supreme stands out from the rest of the vehicles. Paired t-tests were performed similar to the uniform speed scenario. Here, out of 20 comparisons of means, 13 cases showed no statistical difference with those of the composite vehicle.

The above simulation runs for the uniform speed and STOP sign scenario were performed using only one vehicle. To render the tests more realistic, runs were made employing multiple vehicles (150 vehicles) and the fuel consumption and emission statistics computed for the same scenarios. Here, two sets of runs were made – one

with composite vehicles and the other with mixed vehicles. Mixed vehicles composed of one-eighth of the each of the eight vehicle types. The objective here was to evaluate how close the energy and emission estimates of an average composite vehicle are to the results of explicitly modeling the individual vehicles that constitute this composite vehicle. The comparison graphs for these cases are shown in Figure 5. Paired t-tests were conducted to determine whether the means of fuel consumption and emissions for the composite vehicles were different from those of the mixed vehicles. The results indicate that the means (for fuel consumption, HC, CO and NOx) are not statistically different at a 5 percent level of significance. More importantly, the variation in vehicle fuel consumption and emission rates as a function of the roadway free-speed are consistent for the explicit vehicle modeling scenario and the composite vehicle scenario.

Signal Scenario

This scenario incorporated signals at the three intersections of the network. The network used earlier was slightly modified by making the central two sections 0.35 km in length. This was intended to minimize any platoon dispersion that could occur when vehicles leave a traffic signal. The signal offsets were varied from 0 to 40 seconds. Again, two sets of runs were made – one for the mixed vehicles and the other for an entire vehicle fleet composed of an average composite vehicle. Figure 6 illustrates the variations in total travel time, HC, CO and NOx emissions as a function of the traffic signal offset. Paired t-tests were conducted to determine whether the means of travel times and emissions for the composite vehicles were different from those for the mixed vehicles. The results indicate that the means (for total travel times, and NOx) are not statistically different, while those for HC and CO were statistically different at a 5 percent level of significance. Again, the variation in vehicle emissions as a function of the traffic signal offset demonstrates a level of consistency between the two scenarios, as demonstrated in Figure 6.

Further tests on above lines for an area-wide network with different proportions of various types of vehicles in the mix will shed further light on the merits of using composite vehicles vis-à-vis the explicit modeling of the vehicle types that constitute the average vehicle. These are beyond the scope of the paper but are recommended for future work. However, a potential strategy that could be employed in environmental impact studies is to use the INTEGRATION model, exploiting its powerful features in simulating traffic over a network. One of the crucial pieces of information that is required in simulating traffic movements is the Origin-Destination (O-D) pattern for the study area. This information is often obtain, since it requires expensive, labor intensive and time consuming surveys. In such situations, INTEGRATION model can use its inbuilt module QueensOD, which can establish a synthetic O-D table utilizing link volume data which are more easily available. Thus, the strategy could be to collect the link volume data sample (or use the data if available) for O-D modeling and in the process examine the proportions of various types of vehicles using the network. This will help in evaluating the appropriateness of using composite vehicles (as in this study). As an alternative, the INTEGRATION model also permits the use of various types of vehicles and their characteristics in the modeling process. When O-D vehicular trips are simulated, the model will yield area-wide fuel consumption and emission estimates (in addition to other traffic parameters), which are valuable in determining the environmental impacts in the area. Thus, the power and flexibility of INTEGRATION can be exploited advantageously.

CONCLUSIONS

This research study was conceived to evaluate vehicle aggregation impacts on the fuel consumption and emissions as they relate to road transport. Specifically, a composite vehicle (average of eight different individual vehicles) was tested for its fuel consumption and emission rates vis-à-vis the explicit modeling of its constituent eight vehicles (five light duty vehicles and three light duty trucks). The evaluation was conducted using the INTEGRATION simulation model on a hypothetical linear network representing an arterial road. Test scenarios included simulation of a single vehicle as well as multiple vehicles in conjunction with different types of traffic control scenarios (no-control, STOP sign controlled, and traffic signal controlled). The results demonstrate that the use of an average composite vehicle as opposed to the explicit modeling of the vehicles results in vehicle emissions that may differ in absolute terms, however, these differences did not alter any conclusions of the studies. In other words, the use of an average composite vehicle did not alter the trends that were observed in the case of the explicit modeling of individual vehicles.

Consequently, based on this limited study, it appears that the modeling of an average composite vehicle produces results that are consistent with the explicit modeling of individual vehicles. However, further testing of the proposed hypothesis is required for different and larger networks. The findings are believed to be useful in developing modeling strategies in network evaluation studies. This research work has also demonstrated the applicability of the INTEGRATION software for the analysis of fuel consumption and emission impacts of transportation projects.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the ITS Implementation Center in conducting this research.

REFERENCES

1. Van Aerde and Associates. (1999). "INTEGRATION Release 2.20 for WINDOWS: User's Guide – Volume I: Fundamental Model Features." M. Van Aerde and Associates, Ltd., Blacksburg, VA, USA.
2. Van Aerde and Associates. (1999). "INTEGRATION Release 2.20 for WINDOWS: User's Guide – Volume II: Advanced Model Features." M. Van Aerde and Associates, Ltd., Blacksburg, VA, USA.
3. NRC (1995). "Expanding Metropolitan Highways: Implications for Air Quality and Energy Use." Committee for Study of Impacts of Highway Capacity Improvements on Air Quality and Energy Consumption, Transportation Research Board, National Research Council, Washington, D.C.
4. Guensler, R., S. Washington, et al. (1993). "A Weighted Disaggregate Approach To Modeling Speed Correction Factors". Presented at the 72nd Annual Meeting of the Transportation Research Board, Washington, D.C.
5. Rakha, H., Van Aerde, M., Ahn, K., and Trani, A. A. (2000). "Requirements for Evaluating Traffic Signal Control Impacts on Energy and Emissions Based on Instantaneous Speed and Acceleration Measurements." *Transportation Research Record 1738*, TRB, National Research Council, Washington, D.C., pp. 56-67.
6. Ahn, K., Rakha, H., Trani, A., and M. Van Aerde, M. (2002). "Estimating the Vehicle Fuel Consumption and Emissions Based on Instantaneous Speed and Acceleration Levels." *Journal of Transportation Engineering*, 128(2), pp. 182-190.

7. Rakha H., Ahn K., and Trani A. (In press), "The VT-Micro Framework for Modeling of Hot Stabilized Light Duty Vehicle and Truck Emissions." Transportation Research: Part D.
8. Rakha, H., Medina, A., Sin, H., Dion, F., Van Aerde, M., and Jenq, J. (2000). "Traffic Signal Coordination Across Jurisdictional Boundaries: Field Evaluation of Efficiency, Energy, Environmental, and Safety Impacts." *Transportation Research Record 1727*, TRB, National Research Council, Washington, D.C., pp.42-51.
9. Rakha H. and Ahn, K. (2003), "The INTEGRATION Modeling Framework for Estimating Mobile Source Emissions." Accepted for publication in the ASCE Journal of Transportation Engineering.
10. Van Aerde, M. (1985). "Modeling of Traffic Flows, Assignment and Queuing in Integrated Freeway/Traffic Signal Networks." Ph.D. Thesis, University of Waterloo, Waterloo, Ontario, Canada.
11. Van Aerde, M. and Yagar, S. (1988). "Dynamic Integrated Freeway/Traffic Signal Networks: A Routine-Based Modeling Approach." *Transp. Res.*, Part A, 22 (6), 445-453.
12. Van Aerde, M. and Yagar, S. (1990). "Combining Traffic Management and Driver Information in Integrated Traffic Networks." *Proc., 3rd Int. Conf. on Road Traffic Control*, IEEE Conf. Publication No. 320, IEEE, Michael Faraday House, Stevenage, England, 11-15.
13. Rakha, H., and Van Aerde, M. (1996). "Comparison of Simulation Modules of TRANSYT and INTEGRATION Models." *Transp. Res. Rec. 1566*, Transp. Res. Board, Nat. Res. Council, Washington, D.C., 1-7.
14. Van Aerde, M., Hellinga, B., Baker, M., and Rakha, H. (1996). "INTEGRATION: Overview of Simulation Features." *Presented at the 75th Annual Meeting of the Transp. Res. Board*, Washington, D.C., USA.
15. Rilett, L.R., Van Aerde, M, Mackinnon, G., and Krage, M. (1991). "Simulating the TravTek Route Guidance Logic using the INTEGRATION Traffic Model." *Proc., Vehicle Navigation and Information Systems Conf.*, SAE Conf. Proceedings No. 253, Part 2, SAE, Warrendale, Pa., USA, 775-787.
16. Hellinga, B., and Van Aerde, M. (1994). "An Overview of a Simulation Study of the Highway 401 Freeway Traffic Management System." *Canadian Journal of Civil Engineering*, 21, 439-454.
17. Rakha, H., Van Aerde, M., Bloomberg, L., and Huang, X. (1998). "Construction and Calibration of a Large-Scale Microsimulation Model of the Salt Lake Area." *Transp. Res. Rec. 1644*, Transp. Res. Board, Nat. Res. Council, Washington, D.C, 93-102.
18. Van Aerde, M. and Baker, M. (1993). "Modeling Fuel Consumption and Vehicle Emissions for the TravTek System." *Proc., 4th IEEE-IEE Vehicle Navigation and Informations System Conf.*, Published by IEEE, Piscataway, N.J., 126-129.
19. West, B., McGill, R., Hodgson, J., Sluder, S., and Smith, D. (1997). "Development of Data-Based Light-Duty Modal Emissions and Fuel Consumption Models." Society of Automotive Engineers, Paper No. 972910.

LIST OF TABLES

TABLE 1: TEST SCENARIOS

TABLE 2: TEST VEHICLE TYPES AND THEIR SPECIFICATIONS (SOURCE: (18))

LIST OF FIGURES

FIGURE 1: OVERVIEW OF METHODOLOGY

FIGURE 2: TEST NETWORK

FIGURE 3: VARIATION IN FUEL CONSUMPTION AND EMISSIONS (UNIFORM SPEED SCENARIO) (SINGLE VEHICLE)

FIGURE 4: VARIATION IN FUEL CONSUMPTION AND EMISSIONS WITH SPEED (STOP SIGN SCENARIO) (SINGLE VEHICLE)

FIGURE 5: VARIATION IN FUEL CONSUMPTION AND EMISSIONS (STOP SIGN SCENARIO) (MIXED VS. COMPOSITE VEHICLES)

FIGURE 6: VARIATIONS IN TRAVEL TIMES AND EMISSIONS (SIGNAL SCENARIO) (MIXED VS. COMPOSITE VEHICLES)

Table 1: Test Scenarios

Speed (km/h)	Single Vehicle		Multiple Vehicles	
	Veh. Type	Control	Veh. Type	Control
25	1,2,4,5,7,8	No-stop	Composite ^a	Stop
	1,2,4,5,7,8	Stop	Mixed ^b	Stop
50	1,2,4,5,7,8	No-stop	Composite	Stop
	1,2,4,5,7,8	Stop	Mixed	Stop
75	1,2,4,5,7,8	No-stop	Composite	Stop
	1,2,4,5,7,8	Stop	Mixed	Stop
100	1,2,4,5,7,8	No-stop	Composite	Stop
	1,2,4,5,7,8	Stop	Mixed	Stop

a-Composite LDV (average of five LDVs and three LDTs shown in Table 2).

b-Mixed traffic stream includes 12.5 percent of all 8 vehicle types.

Table 2: Test Vehicle Types and Their Specifications (Source: (19))

Year	Make/Model	Engine	Transmission	Curb Weight (kg)	Rated Power (hp)
Light-Duty Cars					
1988	Chevrolet Corsica	2.8L pushrod V6, PFI	M5	1209	130
1994	Oldsmobile Cutlass Supreme	3.4L DOHC V6, PFI	L4	1492	210
1994	Oldsmobile 88	3.8L pushrod V6, PFI	L4	1523	170
1995	Geo Prizm	1.6L OHC I4, PFI	L4	1116	105
1993	Subaru Legacy	2.2L DOHC flat 4, PFI	L4	1270	130
	ORNL LDV average	2.8L, 5.2 cyl.		1322	149
1995	LDV industry average	2.9L, 5.4 cyl.		1315	
Light-Duty Trucks					
1994	Mercury Villager Van	3.0L pushrod V6, PFI	L4	1823	151
1994	Jeep Grand Cherokee	4.0L pushrod I6, PFI	L4	1732	190
1994	Chevrolet Silverado Pickup	5.7L pushrod V8, TBI	L4	1823	200
	ORNL LDT average	4.2L, 6.7 cyl		1793	180
1995	LDT industry average	4.6L, 6.5 cyl			
	8-vehicle average	3.3L, 5.8 cyl		1497	160
1995	LDV+LDT, industry avg.	3.5L, 5.8 cyl			

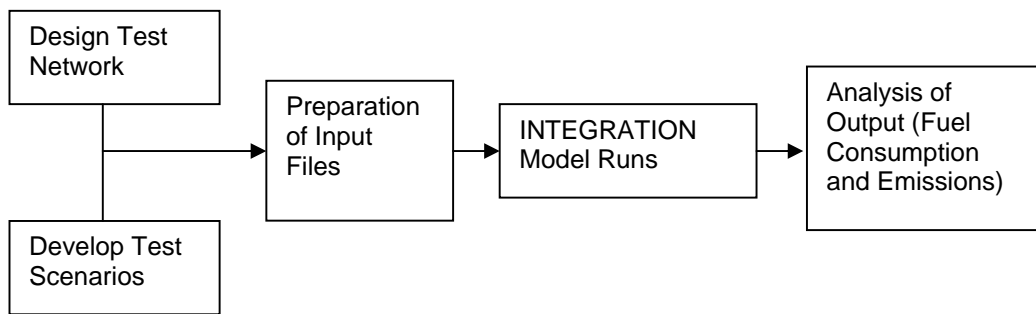


Figure 1: Overview of Methodology

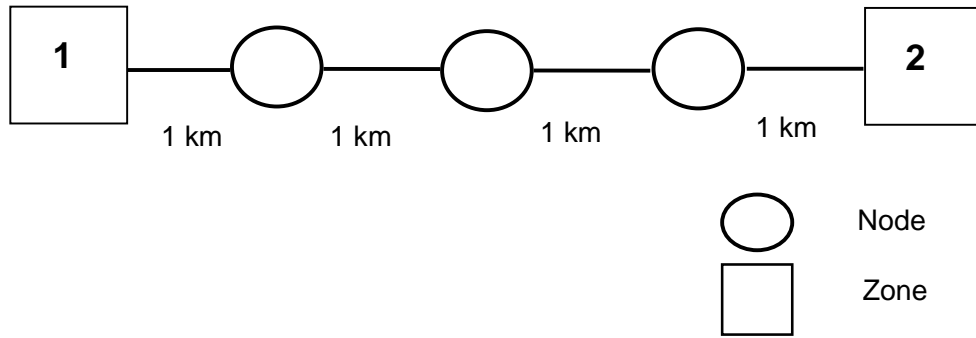


Figure 2: Test Network

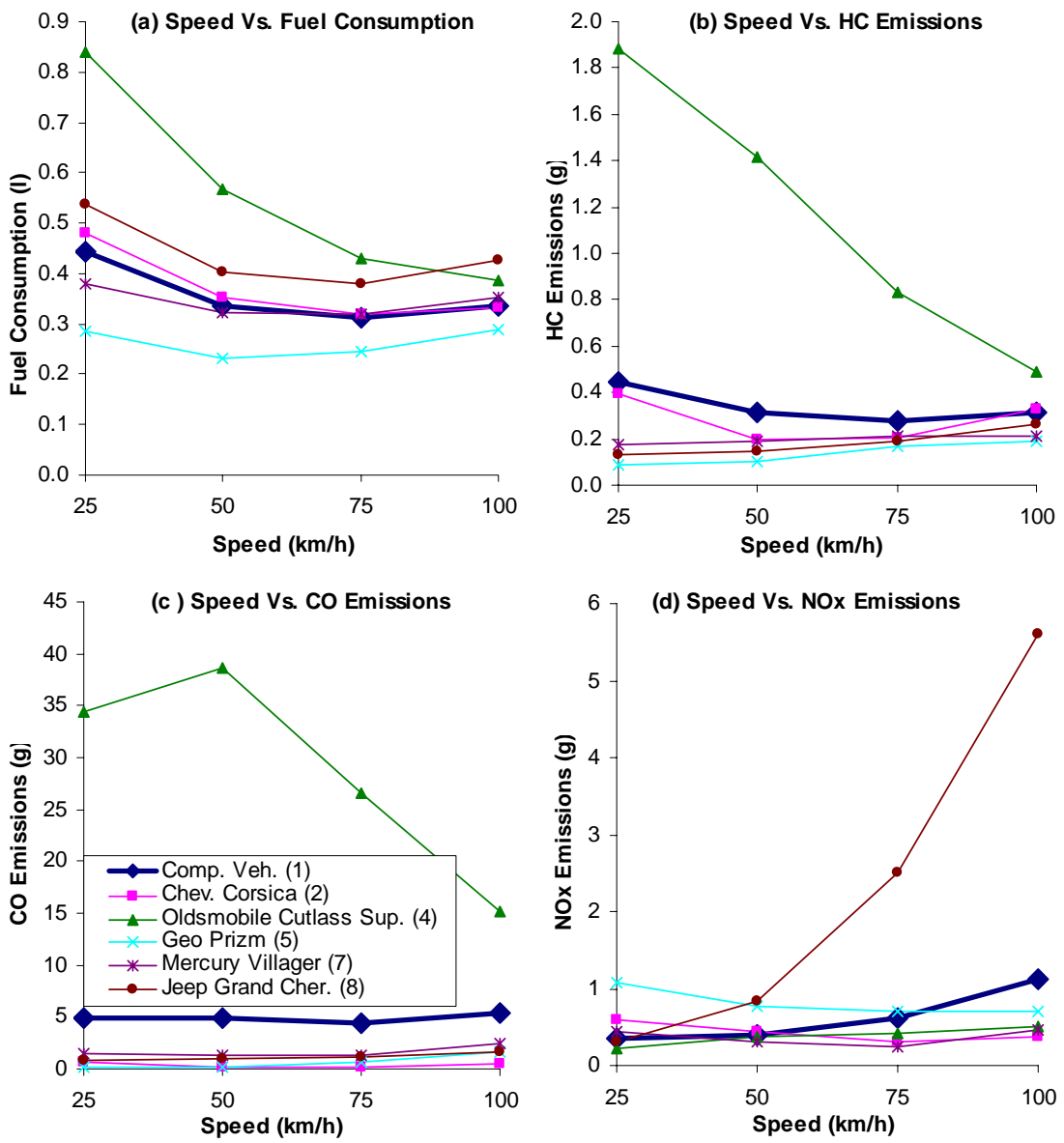


Figure 3: Variation in Fuel Consumption and Emissions (Uniform Speed Scenario) (Single Vehicle)

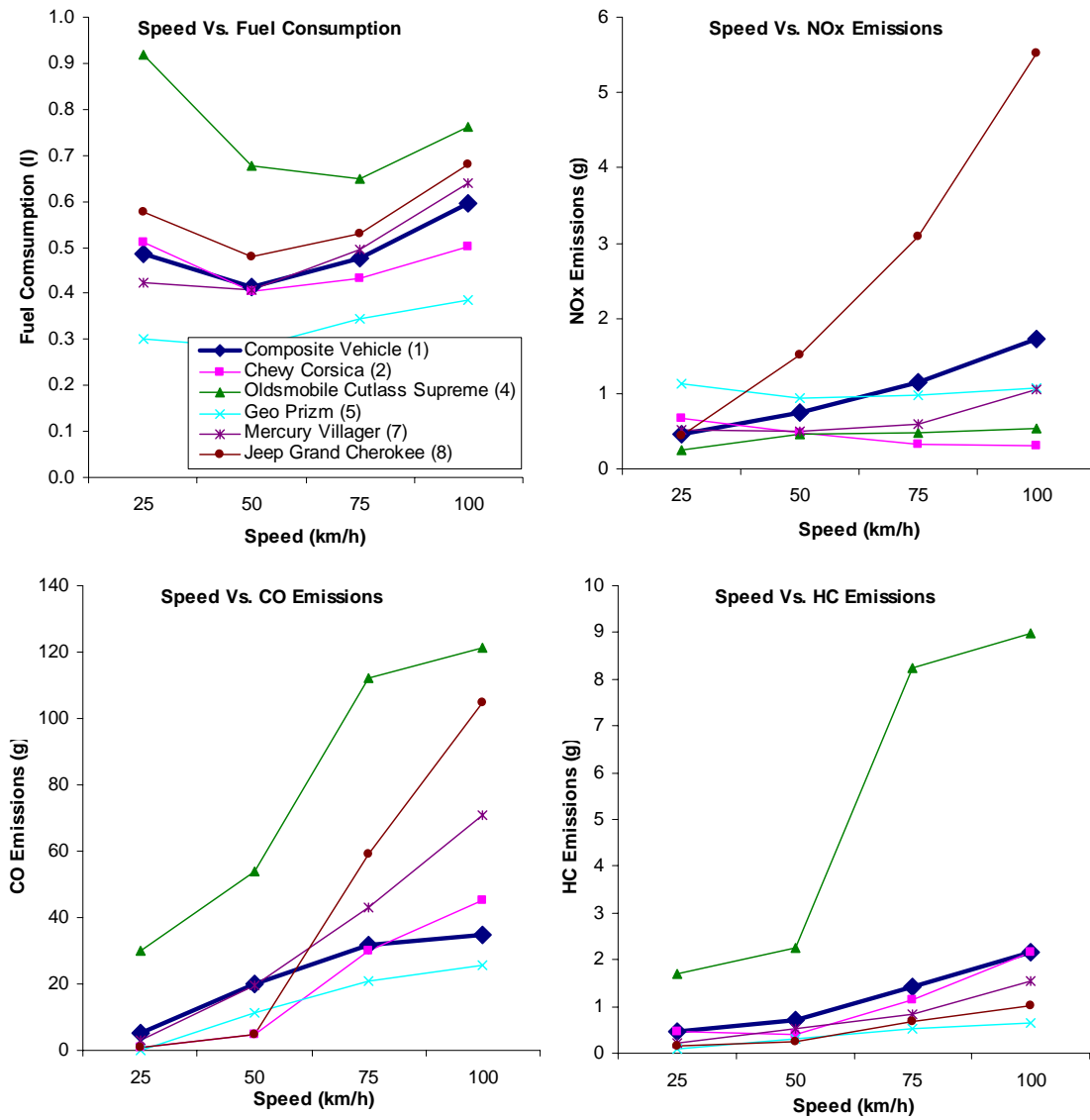
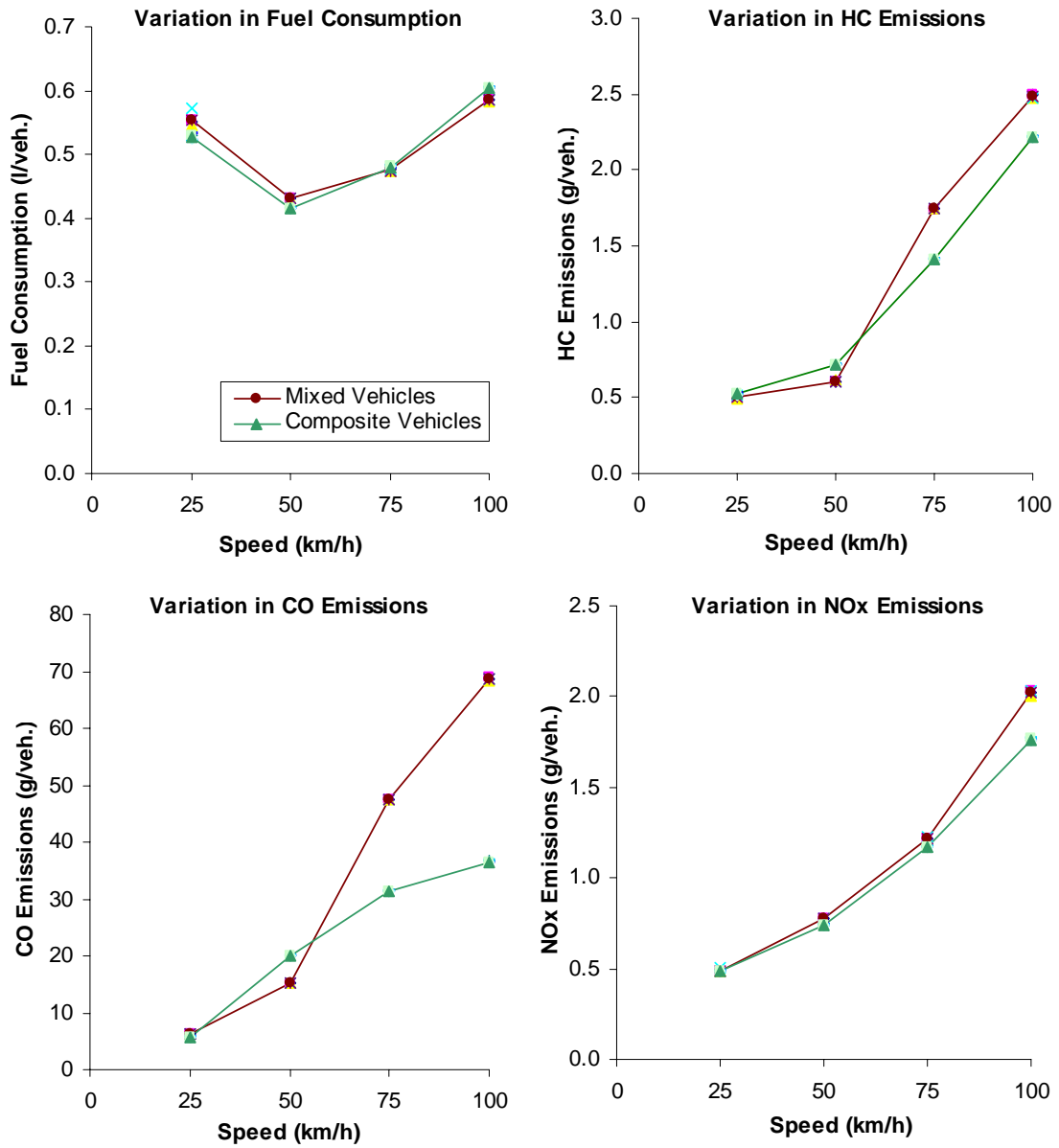


Figure 4: Variation in Fuel Consumption and Emissions with Speed (Stop Sign Scenario) (Single Vehicle)



**Figure 5: Variation in Fuel Consumption and Emissions (STOP Sign Scenario)
(Mixed Vs. Composite Vehicles)**

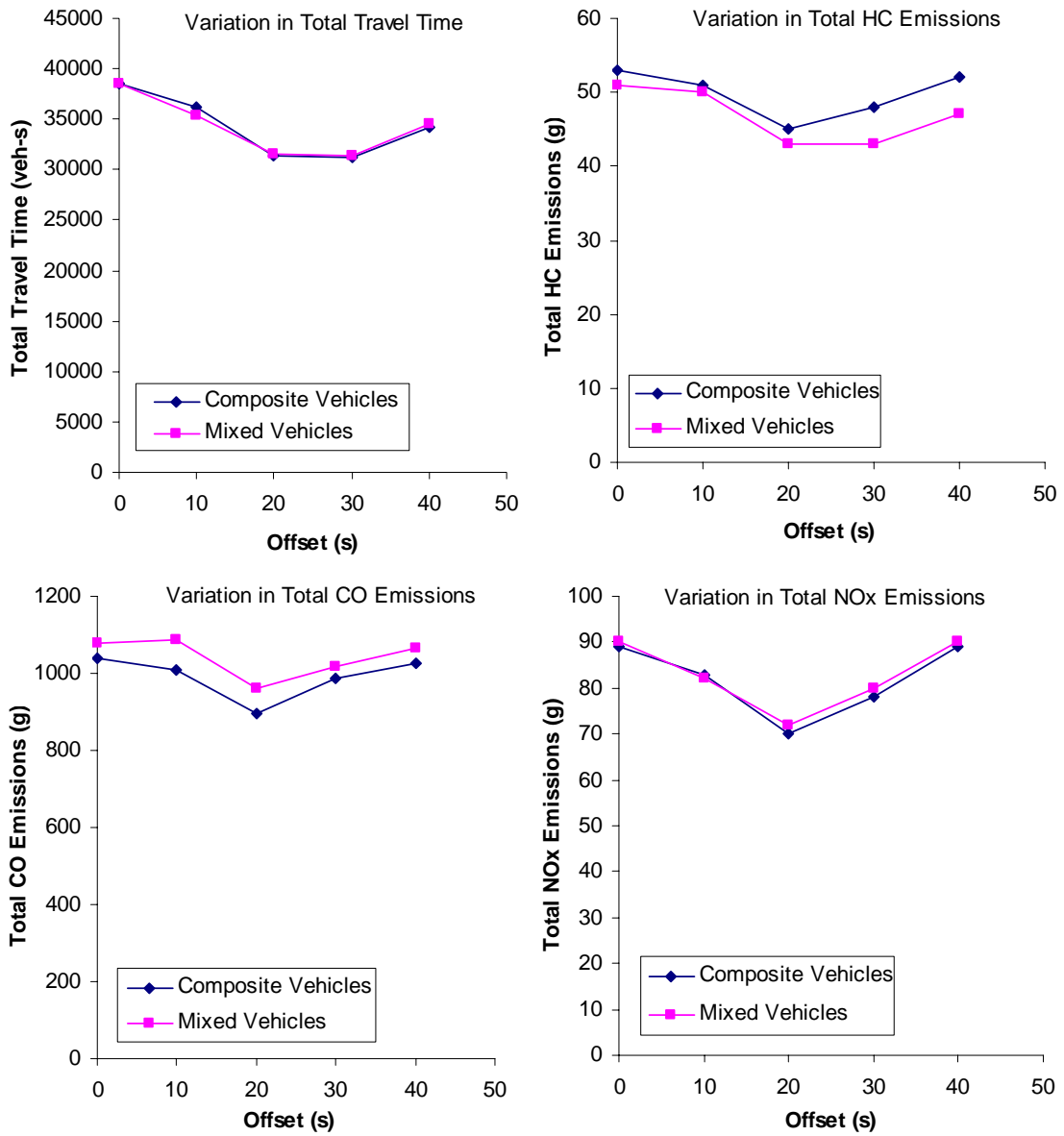


Figure 6: Variations in Travel Times and Emissions (Signal Scenario) (Mixed Vs. Composite vehicles)