

## **Next Generation Human-in-the-loop Transportation Simulation Modeling with Application to Eco-Driving Evaluation**

**Kevin F. Hulme, Ph.D.**  
NYSCEDII  
Buffalo, NY  
hulme@buffalo.edu

**Shan Huang**  
University at Buffalo  
Buffalo, NY  
sh93@buffalo.edu

**Adel W. Sadek, Ph.D.**  
University at Buffalo  
Buffalo, NY  
asadek@buffalo.edu

**Chunming Qiao, Ph.D.**  
University at Buffalo  
Buffalo, NY  
qiao@computer.org

### **ABSTRACT**

The transportation community has long used two distinct simulator types without any formal integration between them. First, are microscopic Traffic Simulation (TS) models, which simulate the movement of individual vehicles based on car-following and lane-changing models, and which have been used to evaluate the operational efficiency of transportation networks. Second, are Driving Simulators (DS), which have been used to examine individual human subjects within a virtual environment. The current research develops a prototype human-in-the-loop transportation simulation modeling framework by integrating these heterogeneous simulation platforms, whose specifications are often in direct opposition. To illustrate the feasibility of the approach, a prototype simulator is developed by integrating a commercial state-of-the-art traffic simulation model with a Driving Simulator custom-developed by the present research team. The prototype system allows the human driver to control (i.e. drive) a subject vehicle in the virtual traffic simulation environment. At the same time, the background traffic that the human driver sees and drives amongst is that resulting from the macroscopic TS, which now intelligently responds to the actions made by the human driver. This capacity helps to broaden the range of applications to which either type of simulators is applicable. As a pilot application for the present study, the prototype integrated simulator is used in conjunction with a fuel consumption and tailpipe emissions model for a small group of subject drivers. In this study, several human subjects are asked to drive a simulated real-world course twice, once each in two levels of traffic congestion. The paper concludes by suggesting possible refinements to the developed prototype, including a real-time networking capacity that will allow multiple human participants to simultaneously interact within our integrated environment. Such a feature is prevalent in entertainment gaming environments, but absent, to date, in research-minded, vehicle simulation and training applications.

### **ABOUT THE AUTHORS**

**Kevin F. Hulme** is a Senior Research Associate at the New York State Center for Engineering Design and Industrial Innovation (NYSCEDII), and is currently the technical lead in NYSCEDII's Motion Simulation Laboratory. He received his B.S., M.S., and Ph.D. at the State University of New York at Buffalo in Mechanical Engineering, with a specialty in design, simulation, and multidisciplinary optimization.

**Shan Huang** is a Ph.D. candidate with the Civil, Structural, and Environmental Engineering Department at the University at Buffalo. His research specialty is Transportation Systems Engineering, and his major interests include: Intelligent Transportation Systems, Artificial Intelligence, and traffic simulation.

**Adel W. Sadek** is an Associate Professor with the Civil, Structural, and Environmental Engineering Department at the University at Buffalo. He received his B.S. in Civil Engineering from the University of Alexandria (Egypt), and his M.S. and Ph.D. from the University of Virginia, Charlottesville. His current research interests include: Transportation Systems Modeling and Simulation; Intelligent Transportation Systems; Artificial Intelligence and Advanced Computing Applications in Transportation; Traffic Engineering, and Infrastructure Management.

**Chunming Qiao** is a Professor with the Department of Computer Science and Engineering at the University at Buffalo. There, he directs the Laboratory for Advanced Network Design, Analysis, and Research (LANDER), which conducts cutting-edge research work on optical networks, wireless and mobile networks, survivable networks, and TCP/IP technologies.

## Next Generation Human-in-the-loop Transportation Simulation Modeling with Application to Eco-Driving Evaluation

Kevin F. Hulme, Ph.D.  
NYSCEDII  
Buffalo, NY  
hulme@buffalo.edu

Shan Huang  
University at Buffalo  
Buffalo, NY  
sh93@buffalo.edu

Adel W. Sadek, Ph.D.  
University at Buffalo  
Buffalo, NY  
asadek@buffalo.edu

Chunming Qiao, Ph.D.  
University at Buffalo  
Buffalo, NY  
qiao@computer.org

### INTRODUCTION

The transportation community has long used two simulator types, but with each operating separately with no true integration. Primarily, the community uses microscopic traffic simulation (TS) models that simulate the movement of individual driver-vehicle units (DVUs) based on car-following and lane-changing theories. TS models have typically been used for evaluating the system performance of transportation networks, primarily from an operational efficiency standpoint (TRB, 2000). In addition, driving simulators (DSs) have been used for the direct testing of individual human subjects (i.e. drivers) within a virtual and motion-based environment.

As expected, each model (used individually) has its own limitations. While TS models allow for capturing dynamics of full-scale traffic networks, they lack behavioral realism, since vehicle movements are based on car-following and lane-changing theories that are often simplifications of reality. This, in turn, limits the application of TS models to the analysis of the transportation system mainly from an operational efficiency standpoint, however pays little regard to safety considerations. As pointed out by Archer (2000), existing microscopic simulation models based on available car following, gap-acceptance, and lane-changing models lack the level-of-detail required for safety evaluations, which demand models that reflect errors in drivers' perception, decision-making, and actions (Cunto and Saccomanno, 2006).

Driving and other vehicle-based simulation hardware/software arrangements, on the other hand, often lack authenticity. In a majority of DSs, for example, accompanying traffic is pre-programmed and does not react to the real-time actions of the live human subject who is operating the simulation. Moreover, their lack of network realism limits their applications to a small subset of vehicle scenarios, and to single site or "local" situations (e.g. a given roadway intersection) versus macroscopic, transportation system-level evaluations.

An interesting concept -- whose implementation has not yet been fully realized -- is the prospect of providing a two-way link between microscopic TS models and DSs (e.g. Pursula, 1999; Ikeuchi et al., 2005). The TS environment would provide for a realistic representation of the transportation network and the prevailing traffic conditions (e.g., congestion levels, availability of gaps, speeds, queues, etc.), beyond what is currently possible using a DS alone. On the other hand, input from the DS would provide for a more accurate modeling of actual driver behavior, instead of primarily depending upon models that have been calibrated elsewhere. This becomes particularly important for understanding how an individual driver's behavior may impact system-level performance; for example, to analyze the behavior of special groups within the driver population (e.g. elderly drivers or teenage drivers), for assessing how driver behavior and habits affect fuel-consumption and emissions (i.e. "Eco-driving") given a realistic traffic environment, and for studying the impact of advanced vehicle telematics on system performance. Moreover, linking TS and DS will help open the door for using microscopic simulation in safety analysis, since in such a case, driver behavior would be factual, and based on real-time human input from the DS.

### BACKGROUND

This section presents a background on the state-of-the-art on driving simulators (and current applications), microscopic traffic simulation (and current applications), and finally, the limited number of attempts at integrating these disparate paradigms.

#### Driving Simulation: state-of-the-art

Obviously, the most authentic experience in vehicle-related research studies is to have humans operate an actual vehicle, perform specific maneuvers, collect data, perform analyses, and make observations. Cost, time, safety, and other constraints deem this option impractical for most applications. An alternative solution is to employ vehicle-based simulation.

In the specific case of road vehicles, a typical driving simulator will consist of driver controls that dictate the driven course of the human operated vehicle. These controls could range from a simple keyboard/mouse on a desktop PC, to a more sophisticated and authentic game-based steering wheel and pedals. The display environment for such a simulator might be in the form of a single desktop monitor, or multiple “life size” display screens that surround and “immerse” the human driver. Many realistic driving simulators also provide audio cues resulting from sounds that originate both interior and exterior to the vehicle cabin.

A modern-day driving simulator could be of the fixed-base variety (i.e., it is “stationary”), or the more advanced simulators may include a moving base within which the human driver is seated and operates the simulator. Such a motion platform, parallel manipulator, or Stewart Platform (Stewart, 1965), is a powered, mechanical, self-contained system for the execution of motion-based simulation and are described by the number of degrees-of-freedom (DOF) that can be simulated by the hardware. Such systems are commonly used for motion simulation and training activities in various applications, including flight simulation (e.g., Baret, 1978), spacecraft training (e.g., Claudinon and Lievre, 1985), and amusement rides and location-based entertainment (e.g., SMS, 2003).

Driving simulators are present at a moderate number of Universities across North America. A few of the major facilities include the National Advanced Driving Simulator (NADS) at the University of Iowa, University of Michigan’s Transportation Research Institute (UMTRI), and Virginia Tech’s Transportation Institute (VTTI). Major commercial driving simulators that include system hardware and software include: DriveSafety, STISIM, and VirtualDriver.

One major limitation with a majority of existing driving simulators is that they lack network realism. Background traffic is non-intelligent and pre-programmed, and therefore does not respond to the actions (or reactions) of the human driver, in real-time. This primary deficiency limits the application of these driving simulators to a subset of scenarios that are limited to single site or local situations (e.g., a particular intersection) without substantial neighboring traffic vehicles, such as would be required by transportation system-level evaluations.

### **Traffic Simulation: state-of-the-art**

Recently, there has been a growing interest among the transportation community in the use of microscopic

traffic simulation modeling for evaluating the system performance of transportation networks, as recognized by the Highway Capacity Manual 2000 (Transportation Research Board, 2000). Microscopic simulation models simulate the movement of individual DVUs based on car-following and lane-changing theories. Interactions among those DVUs then help define the overall transportation system performance, in terms of measures such as average speed, delay, queue lengths, etc. Over the years, a number of car following models have been proposed and evaluated, typically using test vehicles on test tracks (Gartner et. al., 2005).

In terms of applications, microscopic traffic simulation models are typically used to evaluate alternative traffic management strategies (e.g. signal timing changes), new designs (e.g. roundabouts), as well as an element in the design process itself. Moreover, with recent advances in computational hardware and software, it is now possible to use microscopic traffic simulation to construct simulation models of large-scale or regional transportation networks. These regional models could then be used to develop effective dynamic routing strategies in case of evacuations and major accidents and to evaluate system-wide impacts of proposed major capacity improvement projects. Examples of state-of-the-art microscopic simulation models include PARAMICS (Quadstone, 2004), VISSIM (PTV-AG, 2004), and AIMSUN (Barcelo and Ferrer, 1998).

While the use of microscopic traffic simulation has historically focused on the analysis of the transportation system efficiency and operations, recently there has been an increased interest in its use in traffic safety and traffic conflict analysis (Cunto and Saccomanno, 2006). One challenge, however, with this is the complex and multi-disciplinary nature of road-user behavior. As pointed out by Archer (2000), existing microscopic simulation model based on available car following, gap-acceptance, and lane change models may lack the level of detail required for safety evaluations, which demand models that reflect errors in drivers’ perception, decision-making and action.

### **Previous attempts at TS-DS Integration**

As was previously mentioned, the concept of linking together these two research areas – driving and traffic simulation – has been attracting increased attention. Despite various efforts over the last decade, there are still several research questions that need to be addressed. In an early research attempt, Pursula (1999) describes the concept and its advantages, but does not elaborate on any technical details. Ikeuchi et al. (2005)

describe an ambitious research program in Japan aimed at constructing a “Mixed Reality Traffic Experiment Space”, which indeed involves linking driving simulators with traffic simulation models. However, the paper does not offer much in the way of specific technical details, specifically those relating to implementation. Jin and Lam (2003) propose integrating VISSIM with a driving simulator to study the impacts of Intelligent Transportation Systems (ITS). Jenkins (2005) describes a case study of integrating the PARAMICS model with a driving simulator, and discusses the shortcomings of the approach. Finally, a paper by Ciuffo et al. (2009) discusses the challenges of integrating driving and traffic simulation, and presents some first solutions to some of the problems.

### BROADER IMPACTS

The integrated TS-DS framework described in the present research has a wide range of potential applications. In addition to the civilian road vehicle applications emphasized in this work, one can likewise envision using the technology for military training, strategizing, and education. For instance, analogous simulations could be developed that would integrate traffic and “driving” capacities for sea vessels in a watercraft simulation, air vessels in an air battle, or large, slower moving military vehicles (e.g. tanks) for a battlefield simulation on the ground.

As will be seen in the “Future Work” section at the conclusion of this paper, elements of the grand vision for this research are already in development. A few examples are the inclusion of a Network Simulation (NS) as a third component to the TS-DS integration; the capacity for linked simulators, so that multiple vehicle simulators can participate within the same integration simulation environment, even across vast geographic distances; applications pertaining to transportation safety, and infrastructure design; and research studies that analyze human factors and driver/pilot behavior.

### INTEGRATED SIMULATION: EXPERIMENTAL DESIGN

In this section, the designs of the DS/TS are presented; both individually, and as an integrated arrangement.

#### Technical Design: Driving Simulator

The driving simulator implemented for the current study consists, primarily, of a six degree-of-freedom electrically actuated motion platform. Two passengers

are accommodated in a front-seat vehicle passenger cabin (a 1999 Ford Contour). The driver supplies inputs to the simulator using a steering wheel (force feedback, with a 90° rotational stroke), three pressure modulated/adjustable floor pedals (gas, brake, and clutch), and a console gear-shifter with programmable buttons. Additional simulation hardware includes an Emergency-STOP switch, a four-screen (Front, Left, Right, and Rear-view, hexagonally arranged), front-projected XVGA+ visualization system (4:3, 8' x 6', 1400x1050 pixel resolution), and a 2.1 channel stereo sound system. Figure 1 is an image of the exterior of the vehicle cabin and frontward simulation screens.



Figure 1: Motion Simulator

#### Technical Design: Microscopic Traffic Simulator

PARAMICS (v6.0) was selected for this study. It is a suite of microscopic traffic simulation software for modeling freeway and arterial networks. The suite consists of the following three modules: (1) Modeler; (2) Processor; and (3) Analyzer (Quadstone, 2004). *Modeler* is used to define the network of nodes, links and junctions (intersections), as well as the specifics of the traffic demand and vehicle profiles. Simulations can be performed in a high speed non-graphic mode, as well as in 2-D or 3-D visual modes. *Processor* allows multiple simulations for testing various configurations or alternative situations. Finally, *Analyzer* provides various tools to review several measures of effectiveness (MOEs) such as vehicle counts, speed, delay, travel time, and queues.

The primary reason for selecting this particular software as a candidate microscopic traffic simulation model is the fact that it has an add-on module called Programmer, which is a comprehensive development Application Programmer Interface (API). Programmer allows the user to retrieve output values, assign input parameters, and augment the core simulation with new functions and driver behavior. This capability was critical for integrating the TS and DS together.

### Integrated TS-DS

Figure 2 illustrates the general procedure for the TS/DS high-level integration. The human driver sits inside the vehicle, aboard the motion platform (i.e., Figure 1), and provides inputs to the simulation by way of a steering wheel, buttons, paddle shifters (which also serve as an input mechanism for turn signals and lane changing), and both a gas pedal and brake pedal. Once received by the DS client, the user inputs subsequently serve as input to the vehicle dynamics module (VDM).

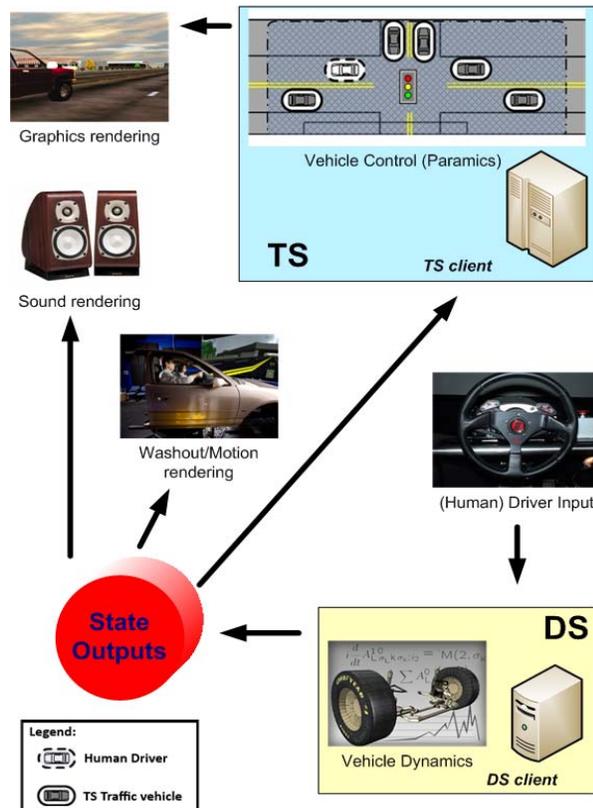


Figure 2. TS-DS Integration (data flow)

At present, the VDM implements the well-known “Bicycle Model” of an automobile (Milliken and Milliken, 1995). This simplified but effective vehicle model treats the pair of tires at each end of the vehicle as a single tire, as shown in Figure 3. There is no roll degree of freedom, so the vehicle will not “fall over”. Subject to the previously described inputs, the vehicle state outputs for the Bicycle Model include: vehicle position and orientation, velocities (current, maximum, and average), accelerations, tire forces, and tire operating conditions.

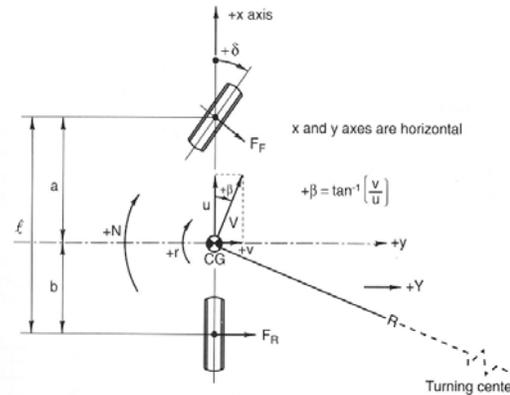


Figure 3. The Bicycle Model of the Automobile

Referring back to Figure 2, the computed state outputs are subsequently used for a variety of purposes. Primarily, they are delivered to the TS such that here, one chosen vehicle’s speed and position/orientation are overridden by the actions of the live driver in the DS. This particular vehicle, which we refer to herein as the subject vehicle, is denoted by a **dashed ellipse** in Figure 2. The subject vehicle’s behavior therefore follows that of the human driver. The subject vehicle is surrounded by other traffic vehicles in the same traffic environment (circled by **solid ellipses**), whose position/orientation are dictated by the TS analysis engine (i.e. these other vehicles traverse the environment using the car following and lane-change models used within the TS). Directly attributable to this integration is the fact that this auxiliary or background traffic now responds in real-time to the actions of the live driver, a feature which was often lacking in stand-alone driving simulator implementations.

For the subject vehicle, overriding the default behavior of the TS was accomplished using a plug-in written in C++ and which utilizes several of PARAMICS custom API’s, and is then compiled into a Dynamic Link Library (DLL). Generally speaking, the developed plug-in provides a capacity to seize full control of a vehicle within the TS (i.e., the vehicle can be dynamically selected by the user using the mouse). From that point onward, the movement of the selected (subject) vehicle mirrors the dynamic output from the DS, which generates and stores real-time vehicle data, including: data point number, time stamp since start of simulation, steering wheel angle, gas pedal position, brake pedal position, vehicle speed, vehicle heading, left paddle shift (on/off), and right paddle shift (on/off).

In the TS, each second in the real world is divided into a number of “simulation intervals” as specified by the user. However, the current version of PARAMICS constrains that number to a maximum of 30 simulation intervals per second. Correspondingly, the DS was set to operate at 30 Hz. to allow for one-to-one synchronization. In this regard, it should be noted that the TS, by default, attempts to execute as rapidly as it can. This means that for a small network and powerful computers, the TS can actually run *faster* than real-time. To maintain synchronization in such cases, the plug-in was designed to wait until notification is received that the output of the DS is updated at each simulation interval.

Besides delivery to the TS environment, the state outputs from the DS are also delivered to two other sources; (see Figure 2). First, for motion processing, the vehicle states must be converted into DOFs - roll, pitch, yaw, heave, surge, and sway. Due to the finite stroke length of each of the motion platform actuators, this conversion involves scaling, limiting, and tilt coordination (e.g., Romano, 2003); sub-processes of a methodology known as washout filtering (e.g., Bowles et al., 1975). The updated DOFs are delivered by the DS client to the motion platform. Once received, the state of the platform is updated, and the platform continues to send datagram packets to the DS client (and vice-versa) for the entire simulation. Second, for audio rendering, OpenAL is implemented, including: vehicle ignition, engine tone (which varies according to the speed/RPMs), squealing tires (which vary in accordance with the calculated slip angles), hazard/danger cues (e.g., a police siren when the speed limit is surpassed), crash cues (e.g., a spinout when the sideslip angle exceeds its allowable limit, or a rollover when the lateral tire normal loads exceed their limits), and vehicle shutdown.

Lastly, for visual feedback, the scene graphics are rendered within PARAMICS, which has 3-D visualization capabilities, including the ability to visualize driver point-of-view at run-time. The scene graphics include: the position/orientation of the human driven vehicle, position/orientation of the traffic vehicles (including visual cues for brake lights and turn signals), the roadway geometry, and traffic signals at intersections. Refer to Figure 4.

For this proof-of-concept implementation, the entire data flow loop (Figure 2) operates at 30 Hertz, which is an inherent limitation of the TS (i.e., current computing power vs. the extent of the calculations required to provide realistic, real-time traffic flow). In future implementations, graphics/audio rendering rates will be

improved to a minimum of 60 Hz., and motion rendering will be increased by an order of magnitude.

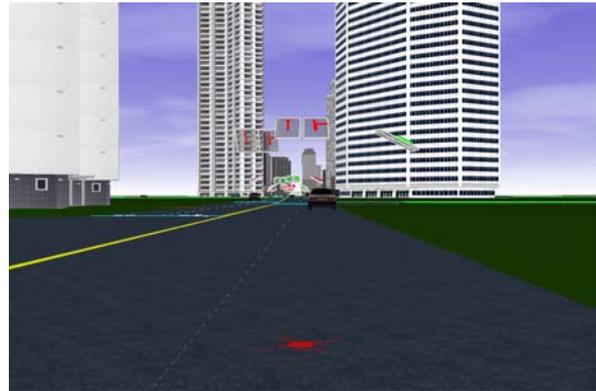


Figure 4 – Scene graphics rendering

### Integration with an Emissions Model

To allow for using the integrated DS-TS platform to evaluate how driving habits can affect fuel consumption and emissions rates, the integrated platform was linked to the Comprehensive Modal Emissions Model (CMEM) developed by the University of California, Riverside (Barth et al., 2001). CMEM represents a significant improvement over current state-of-the-practice emissions models in that it uses a physical, power-demand modal modeling approach. It can be used both for micro-scale as well as macro-scale emissions analysis, and, given a detailed second-by-second velocity profile for a given vehicle, it can predict highly time-resolved fuel consumption and emissions rates.

For the present study, to accentuate fuel consumption and emissions patterns over a short driving distance, we simulated a “light duty truck”, (CMEM vehicle type 17) with “normal” emission patterns. Table 1 summarizes the associated vehicle properties.

Table 1. Vehicle properties for emissions model

Property	Value
Mass (lbs)	3937.50
Coast down power (hp)	17.99
Max Torque (ft-lb)	193.78
Engine speed (rpm)	2953
Engine speed at max power (rpm)	4603
Engine speed at Idle (rpm)	850.0
Engine displacement (L)	3.42
Number of cylinders	4
Engine/vehicle speed (rpm/mph)	33.56
Number of gears	4

## PRELIMINARY RESULTS AND DISCUSSION

### Experimental Setup

The recent years have witnessed an increased interest in eco-driving practices. Eco-driving involves making subtle changes to driving habits in order to reduce fuel consumption and harmful emissions. It includes practices such as avoiding rapid acceleration or braking, driving at posted speed limits, and maintaining a constant speed. It is estimated by EcoDriving<sup>USA</sup>, (2010) that such practices can reduce fuel consumption by up to 15%.

To demonstrate the feasibility of using the integrated simulation platform to evaluate eco-driving applications, and to evaluate the impact of driving habits on fuel consumption and emissions, a simple experiment was designed whereby a total of 16 different drivers were asked to virtually drive within the integrated TS-DS. Demographics were as follows: 14 males and 2 females, average age 27.7 years ( $\sigma = 6.48$ ), and average driving experience of 7.5 years ( $\sigma = 7.46$ ). The 0.75-mile roadway segment, which includes six signalized intersections, was modeled after a collection of roadways located close to the University at Buffalo campus, including modeling of lanes, signal timing parameters, roadway curvature, etc. Refer to Figure 5.

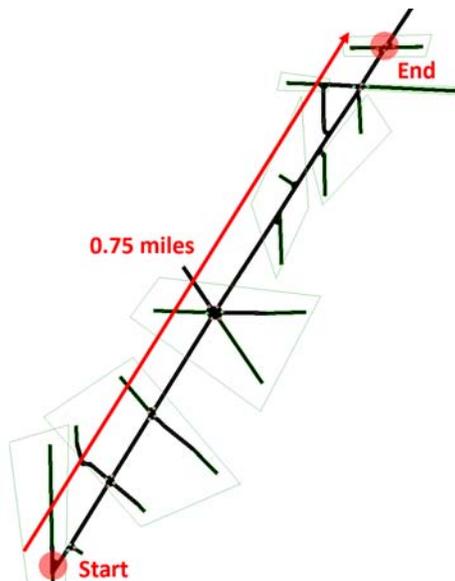


Figure 5 – Integrated TSDS environment

Each human subject was asked to drive the course twice, one time under low congestion conditions, and the second time under slightly congested conditions. The speed profile output from each driver was then

recorded for further analysis using the CMEM Eco-model. The objective from the experiment was to discern whether there were significant performance differences among the different drivers, and whether factors such as years of driving experience or congestion levels had an impact on fuel consumption and average emission rates. Figure 6a illustrates one of the human subjects operating the simulator during the study, and Figure 6b shows the 2 screens that are presented to the driver. The front-center screen shows the environment scene graphics (i.e., the TS), and the front left screen presents travel speed and other relevant information to the dynamics of the subject vehicle (i.e., the DS).



Figure 6a – Human subject aboard simulator



Figure 6b – Integrated TS-DS screen visuals

### Results

Table 2 offers a summary of the driver excursions, under the “low congestion” conditions. The data includes: the driver ID number and his/her number of years driving experience (separated by a **dash** in the Tables), the excursion time (seconds), Maximum and

Average speeds (mph), and Fuel consumption rate and Tailpipe emissions rate (CO<sub>2</sub>), (grams/mile). Note that every liter of gasoline that is burned produces about 2.4 kg of CO<sub>2</sub> (NRC, 2008), and is responsible for over 60% of the enhanced greenhouse effect causing climate change (CCC, 2010).

**Table 2. “Low Congestion” driver data**

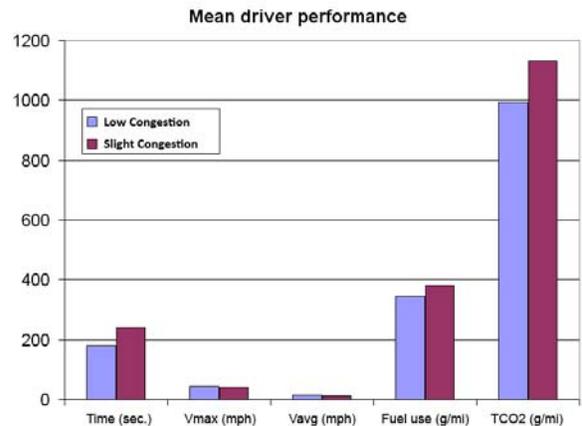
Driver	Time	V <sub>ma</sub> x	V <sub>avg</sub>	Fuel use	T <sub>CO2</sub>
1-1	160	48.3	16.4	406.7	1129.9
2-7	160	43.4	15.8	318.5	997.9
3-15	215	37.3	11.7	355.6	1075.4
4-0	162	49.5	16.3	460.8	1234.4
5-2	215	43.6	12.4	329.7	1015.2
6-3	163	46.0	17.1	395.9	1010.1
7-10	169	42.1	15.3	356.7	1074.8
8-6	162	43.0	16.5	464.3	1259.0
9-4	172	35.4	14.5	245.0	761.6
10-1	216	37.3	11.6	320.5	1004.6
11-20	213	33.5	11.5	293.7	919.4
12-16	161	77.5	17.9	353.7	902.0
13-6	169	41.4	15.2	334.7	971.8
14-24	161	61.8	21.2	357.0	947.8
15-5	162	40.2	16.2	294.7	906.6
16-0	216	30.7	13.7	221.5	694.7
<b>Mean:</b>	179.7	44.4	15.2	344.3	994.1
<b>STD:</b>	24.7	11.4	2.6	66.6	147.9

Table 3 offers a summary of the driver excursions, under the “slight congestion” conditions.

**Table 3. “Slight Congestion” driver data**

Driver	Time	V <sub>ma</sub> x	V <sub>avg</sub>	Fuel use	T <sub>CO2</sub>
1-1	230	43.2	11.2	439.4	1285.8
2-7	231	40.4	10.7	369.1	1156.9
3-15	286	36.2	8.5	351.8	1031.8
4-0	244	50.1	11.7	517.3	1383.8
5-2	252	42.8	11.0	338.6	1042.8
6-3	230	51.9	14.4	321.0	902.6
7-10	226	38.6	11.0	479.2	1447.9
8-6	286	43.0	8.8	549.9	1649.4
9-4	234	39.5	10.9	320.2	1004.4
10-1	231	40.0	11.1	396.9	1194.0
11-20	232	35.4	11.7	272.8	855.1
12-16	228	47.5	14.2	308.3	912.8
13-6	233	39.3	11.4	373.6	1131.9
14-24	231	44.1	11.4	449.7	1263.0
15-5	232	36.3	10.7	375.6	1132.9
16-0	229	24.2	11.1	226.6	709.4
<b>Mean:</b>	239.6	40.8	11.2	380.6	1131.5
<b>STD:</b>	19.1	6.5	1.4	87.9	240.3

By comparing the Mean values between the two tables (and their representative congestion levels), the results are expected. Due to the increased volume of traffic on the road, the mean duration for the ¾ mile excursion increased by 25% (179.7 to 239.6 seconds), and correspondingly, mean maximum and average speeds decreased due to the traffic (by 8.2%, and 25.9%, respectively). More importantly are the Eco driving result estimates from the CMEM model: mean fuel use (rate) increased from 344.3 to 380.6 grams/mile, a 9.5% increase, and mean CO<sub>2</sub> rate emissions at the tailpipe increased from 994.1 to 1131.5 grams/mile, an increase of 12.1%. These expected trends are accentuated by Figure 7, which represents a bar graph of the mean values: an increase in driving duration implies expected decreases in maximum and average speed, and corresponding increases in fuel use and tailpipe emissions.



**Figure 7 – Driver performance summary**

From a “human factors” perspective, some interesting observations were made from the same datasets. Figures 8-9 represent regression plots of fuel use and tailpipe emissions for the Low Congestion and Slight Congestion traffic scenarios, respectively. Although the data has a low correlation coefficient, a general trend can be viewed: a (slight) inverse relationship between both fuel usage and tailpipe emissions versus driver experience (i.e., number of years driving). The results of the regression analyses are displayed on each plot, along with the negative values for slope.

Clearly, this is only a pilot study of small sample size, and of relatively short driving duration (0.75 mile), and performance in a driving simulator is not necessarily indicative of true driver behaviors in an actual motor vehicle. However, the important point to be made here is that in a global effort to decrease fuel consumption

and harmful emissions, an integrated TS-DS simulator incorporated with a numerical emissions model can be a useful tool for examining (and ultimately, improving upon) these types of trends among driver behaviors.

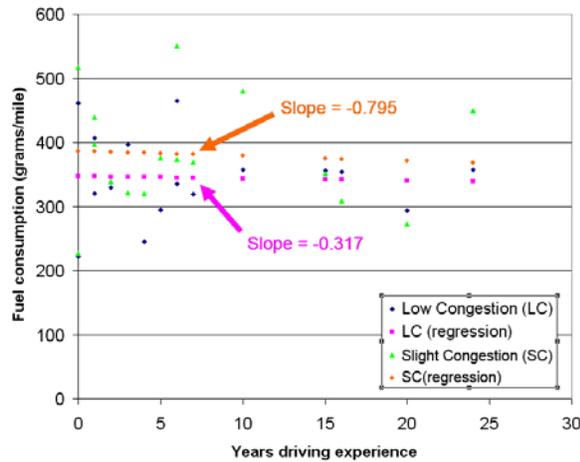


Figure 8 – Fuel use vs. driver experience

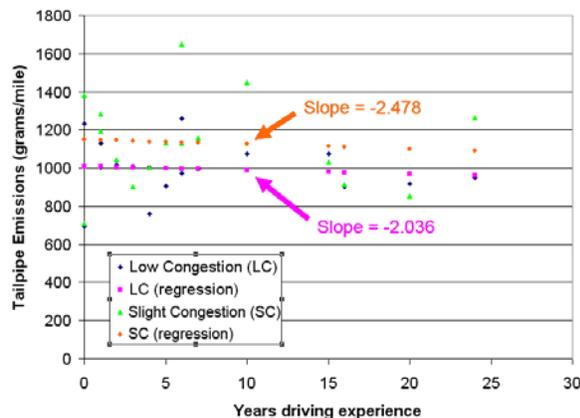


Figure 9 – Tailpipe emissions vs. driver experience

## CONCLUSIONS

The current research describes the development of a prototype transportation simulation modeling framework by integrating two heterogeneous simulation platforms: a traffic simulator and a driving simulator, whose specifications are often in direct opposition. To illustrate the feasibility of the approach, a prototype simulator has been developed by integrating PARAMICS with a custom-developed driving simulation software. The prototype system allows the human driver to “override” (i.e. drive) a subject vehicle in the virtual traffic simulation environment amidst background traffic generated by the traffic simulation.

The integrated simulation capacity developed for this work was merged with the CMEM software for estimating fuel consumption and vehicle emissions. The pilot driving study consisted of 16 human subjects of varying gender, age, and driving experience. Each drove the 0.75 mile road course twice, once for each of two different levels of traffic. The trends exhibited by the data means were expected: an increase in driving duration implies expected decreases in maximum/average speed, and corresponding increases in fuel use and tailpipe emissions. Further preliminary data analyses indicate that an integrated TS-DS simulator can be a useful tool for examining “human factors” among drivers in a global effort to make driving a more “Eco-friendly” practice.

## FUTURE WORK

The TS-DS integration framework presented in this paper is certainly a work in progress. There are numerous potential avenues for its extensibility and expansion, and these are summarized here:

### 1) Integration that includes Network Simulation

The proposed TS-DS integration is the first step towards the development of a more complete simulator integration for transportation research. Namely, an integration that would include a link to Network Simulation (NS), which will take into account messages to and from vehicles to other vehicles, and to and from the highway infrastructure itself. While there have been numerous studies that have attempted to develop integrated TS/NS simulators and a few others that attempted to integrate TS/DS, none has attempted to integrate all three types of simulators. Such an integration would allow a human driver to control a subject vehicle in a virtual transportation environment that is capable of communicating with other vehicles and with the traffic infrastructure (IntelliDrive, 2010), and is also capable of sending relevant warning messages to the driver.

### 2) Multi-participant networked vehicle simulation

When trying to analyze the real-time impact of driver decisions based upon the actions of others (e.g. a driver swerving into another lane, V2V/V2I studies, etc), it would be useful to allow simulation participants to interact – LIVE - with other human participants located within the same simulation environment. Therefore, as a companion to the Integrated TS-DS framework, described in this paper, we envision a server-client architecture that will allow multiple driving simulators to be linked across a network. Each client will be

executing a common instance of the integrated DS/TS environment (e.g., seen in Figure 2) on a local computer. All simulation-relevant information to be exchanged between participants (clients) is relayed through the Server. Certain high frequency communication between clients, such as vehicle position/orientation, can be sent via UDP, where partial error tolerance is more permissible. Other critical data, such as server connection, data messages, and real-time triggered events, are delivered to the server via TCP. The server will then broadcast these packets to all simulation clients (e.g., Figure 10). This integration capacity would not require that all networked simulator participants have access to full motion-based hardware. Drivers would be able to participate in a “graphics only” (fixed-base) networked simulation with only a PC-based steering wheel and pedals as controls - or in the absence of this hardware – even a basic keyboard and mouse.

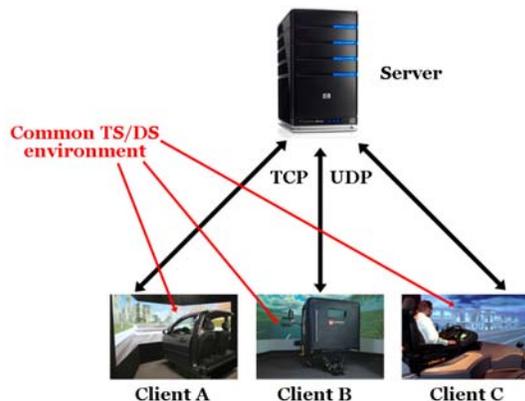


Figure 10 - Multi-client simulation capability

### 3) Transportation Safety Research

Such an integrated cyber-transportation system (CTS) has the potential to dramatically improve transportation safety, efficiency, and energy consumption/vehicle emissions by providing a networked environment supporting wireless Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications, as well as Vehicle-to-Other (V2O) communications (e.g., Bohm et al., 2008). From a traffic safety standpoint, an integrated CTS makes it possible for drivers to receive warning messages in the event of an impending collision, allowing them to take appropriate actions. An Active safety system might intervene, for example, by applying emergency braking to prevent an accident. With respect to traffic operations, an integrated CTS allows for the design of intelligent traffic control algorithms which can reduce travel time, fuel consumption and vehicle emissions by minimizing deceleration and acceleration. For example, with an

intelligent intersection control system, it becomes possible for all approaching CTS-compatible vehicles to be “assigned” a time slot to cross an intersection.

#### 4) Analysis of Human Factors and Driver behavior

A common design objective of an integrated CTS might be to deliver as many warning messages to a driver as possible in the shortest amount of time. However, doing this will potentially cause driver distraction and confusion, resulting in negative impacts. Therefore, a key research question to be answered by the proposed framework is whether it is safe/efficient to rely on human response to an intelligent intersection's recommendations, or whether driver control should be partially relinquished in the vicinity of intersections (e.g., automatic speed control). Another question may pertain to how an intelligent intersection would function in the presence of both human-driven vehicles and autonomous vehicles, as this is to be expected in terms of the natural deployment path of this technology.

#### ACKNOWLEDGEMENTS

NYSCEDII would like to acknowledge continual support from the State of New York, and specifically from the New York State Foundation for Science, Technology and Innovation (NYSTAR).

#### REFERENCES

- Archer, J. (2000). “Developing the potential of micro-simulation modeling for traffic safety assessment”, 13th ICTCT Workshop. Corfu, Greece.
- Barcelo, J. and Ferrer, J. L. (1998). “AIMSUN2: Advanced Interactive Microscopic Simulation for Urban Networks.” Departamento de Estadística e Investigación Operativa, Facultad de Informática, Universidad de Catalunya.
- Baret, M., (1978). “Six degrees of freedom large motion system for flight simulators”, AGARD Conference Proceedings, No. 249, Piloted Aircraft Environment Simulation Techniques, pp. 22-1/22-7.
- Barth, M., F. An, T. Younglove, G. Scora, C. Levine, M. Ross, and T. Wenzel, (2000). “Development of a Comprehensive Modal Emissions Model. Final Report for NCHRP Project 25-11, TRB, National Research Council, Washington, D.C.
- Bohm, M., Pfliegl, R., and Frötscher, A., (2008). “Wireless Infrastructure to Vehicle Communication

Technologies to Increase Road Safety along Motorways”, Transportation Research Record.

Bowles, R.L., Parrish, R.V., and Dieudonne, J.E., (1975). “Coordinated Adaptive Washout for Motion Simulators,” *Journal of Aircraft*, 12(1), pp. 44–50.

Ciuffo, B., Punzo, V., and Torrieri, V. (2009). “Integration of Driving and Traffic Simulation: Issues and First Solutions”, 88th Annual Transportation Research Board Meeting, Washington, D.C.

Claudinon, B. and Lievre, J., (1985). “Test facility for rendezvous and docking”, 36th Congress of the IAF, Stockholm, pp. 1-6.

Climate Change Connection (CCC, 2010). “Tailpipe Emissions”, Manitoba Eco Network, <http://www.climatechangeconnection.org/emissions/Tailpipeemissions.htm>, Copyright 2010.

Cunto, F., and Saccomanno, F.F., (2006). “Evaluation of Safety Countermeasures at Intersections Using Microscopic Simulation”, 85th Annual Transportation Research Board Meeting, Washington, D.C.

EcoDriving<sup>USA</sup>. (2010). Retrieved: June 18, 2010, from <http://www.ecodrivingusa.com/>

Ikeuchi, K., et al., (2005). “Sustainable ITS project overview: mixed reality traffic experiment space under interactive traffic environment for ITS”, proceedings of the 2005 IEEE Intelligent Vehicles Symposium, Issue 6-8, pages 735-738.

Gartner, N., C. J. Messer, and A. K. Rathi (Editors). (2005). *Traffic Flow Theory; A State-of-the-Art Report*. Available at <http://www.tfhrc.gov/its/tft/tft.htm>. Last retrieved on June 18, 2010.

IntelliDrive, (2010). “Intellidrive. Safer. Smarter. Greener.”, <http://www.intellidriveusa.org/>, retrieved May 13, 2010.

Jenkins, J.M., (2005). “Integrating driving simulation and traffic simulation: A case study”, Proceedings of the Annual Conference of the Canadian Society for Civil Engineering.

Jin, M. and Lam, S.-H., (2003). “A Virtual-Reality Based Integrated Driving-Traffic Simulation System to Study the Impacts of Intelligent Transportation Systems (ITS)”, Proceedings of the 2003 International Conference of Cyberworlds, Nanyang, Singapore.

Milliken, W. F. and Whitcomb, D. W., (1956). “General Introduction to a Programme of Dynamic Research,” Proceedings of Auto. Div. Instn Mech. Engrs, 7, pp. 287-309.

Natural Resources Canada (NRC, 2008). “Idling - Frequently Asked Questions”, <http://www.oe.nrcan.gc.ca/communities-government/transportation/municipal-communities/articles/faq.cfm?attr=8>, page last modified November 19, 2008.

PTV-AG., (2004). “Vissim Microscopic Traffic and Transit Simulation User Manual, v.3.70.” Karlsruhe, Germany.

Pursula, M. (1999). “Simulation of Traffic Systems - An Overview”, *Journal of Geographic Information and Decision Analysis*, Vol.3, No.1, pp. 1-8.

Quadstone, Ltd. (2004). “Quadstone PARAMICS v.5.0 Modeler User Guide.” Scotland, UK.

Romano, R., (2003). “Non-linear Optimal Tilt Coordination for Washout Algorithms,” AIAA Modeling and Simulation Technologies Conference and Exhibit, Austin, TX., AIAA 2003-5681.

Silicon Motor Speedway Online (SMS), (2003). “Racing so Real you can Feel it”, (online web link), <http://www.smonline.com/>, All Rights Reserved, 2003.

Stewart, D., (1965). “A platform with six degrees of freedom”, *The Institution of Mechanical Engineers*, 180 (15), pp. 371-384.

Transportation Research Board (TRB), (2000). “Highway Capacity Manual”, TRB, National Research Council, Washington, D.C.