A Validated and Integrated Simulation Framework for Human Factors Analyses

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ABSTRACT

Transportation simulation researchers commonly institute two distinct simulation platforms that are often implemented independent of one another. Traffic Simulation models emulate the macroscopic or mesoscopic behavior of ground vehicles, while Driving Simulators are used to examine microscopic driver behavior within a virtual environment. This research sees the integration of these heterogeneous simulation platforms, which broadens the range of applications for which both simulator types are applicable. The integrated simulation framework has been validated by having several human subjects drive a segment of a signalized arterial in both the artificial environment and on the corresponding real-world roads, during (simulated and actual) rush hour traffic. Various data is collected within the integrated simulation framework, including timestamp, position, velocity, and accelerations, and comparable data is collected (and compared) when the human subjects drive the actual roads.

The described framework is then deployed to focus on Human Factors (e.g., driver acceptance and preference) associated with autonomous control features anticipated in next-generation vehicles. In our experiments, participants were asked to assign the headway to a minimum value that they could "tolerate" (i.e., based on workload, confidence, comfort, safety and acceptance). The results demonstrate that most drivers prefer spacing between vehicles by relying on their judgment on distance, rather than headway (time). Future technology will be able to support autonomous vehicle operations, most likely with an evolving trajectory of acceptance, and the human factors element of accepting the technology may lag the deployment of the technology itself. Accordingly, simulator-based efforts to identify human tolerances on the roads have the potential to help to accelerate the adoption of these advanced autonomous technologies. This is the primary motivation for this study, which will help to inform the design of future autonomous vehicle applications, and will serve as a reference point for optimizing the route capacity of next-generation transportation systems.

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INTRODUCTION

Roadway safety continues to be a major public health concern. Today, more crash avoidance technologies are available to the driving consumer, yet the complexity of human factors still plague our ability to favorably impact roadway safety. According to the National Highway Transportation Safety Administration, 90% of all vehicle crashes involve some element of human error (U.S. DOT, 2013). Thus, developing transportation modes and systems, evaluating efficient transportation behaviors, and ensuring the safety of individuals engaging with the system are critical technological, public health, and public policy aims.

As transportation and M&S experts continue to confront this problem, an interesting concept that has emerged over the last decade is the prospect of providing a two-way integration between microscopic traffic simulation and driving simulators. The traffic simulation environment provides a realistic representation of the transportation network and the prevailing traffic conditions (e.g., congestion levels, availability of gaps, speeds, intersection queues), beyond what is currently possible using a standalone driving simulator. Input from the driving simulation provides for authentic driver behavior, which is particularly important for understanding impact on system-level performance and human factors concerns.

In this research, we attempt to validate our integrated simulator by allowing our test subjects to drive the exact same roadways that have been modeled in our virtual environment. Driver performance data is collected, stored, and analyzed for both virtual and physical scenarios. Comparison of the simulation data to "real world" driving data will allow the artificial environment to be authenticated and fine-tuned over time. Once integrated and validated, we use the simulation framework to address human factors issues that pertain to next-generation vehicle technologies. In this paper, we look specifically at autonomous vehicle technology, as, for some period of time, we forecast that our roads will likely be occupied by BOTH human-driven and partially/fully autonomous vehicles. In the next section, we discuss related work that preempted the research defined in this paper, and also helped to define its requirements.

BACKGROUND AND LITERATURE REVIEW

We decompose our background discussion and related sampling of relevant literature into three subcategories: Individual (standalone) Simulators, Physical Test Beds, and Integrated Simulators.

Individual Simulators

Typical standalone simulators used in transportation research include Driving Simulators (DS) used to monitor driver behavior, performance, and attention, Traffic Simulators (TS) used to better help plan, design and operate transportation systems, and Network Simulators (NS) used to examine communication networks that are particularly difficult or expensive to emulate using real hardware. Each simulator type, when used independently, has its own set of limitations. While TS models allow for capturing the dynamics of large-scale (macro) traffic networks, they often lack driver behavioral (micro) realism, since vehicle movements are based on idealistic car-following and lane-changing models that are often simplifications of reality. An NS commonly provides detailed simulation of communication protocols (e.g., between vehicles and infrastructure), but does not have a realistic vehicle mobility model. A typical DS allows for the analysis of driver behavior within a virtual simulation environment, however, often lack transportation network realism. Accompanying traffic is typically pre-programmed, and does not react according to the real-time actions of the human subject who is operating the human-driven vehicle.

Physical Test Beds

While recent field tests such as the SHRP-2 (TRB, 2014) initiative provide potentially useful naturalistic driving data for transportation safety experts, such data alone is not directly suitable for the analysis of next-generation transportation issues, as it cannot be used to evaluate emerging or unproven technologies (i.e., those that may expose drivers to risky or dangerous situations). This is also true of some of the latest US DOT test beds, such as the Safety Pilot experiment (UMTRI, 2014), and The Connected Vehicle Test Bed (RITA, 2014). These environments are costly to design, construct, and verify, and limited to testing mature technologies. To safely and economically examine emerging and unproven technologies, we continue to rely on M&S.

Integrated Simulators

Due to the deficiencies of most standalone simulators, various researchers have attempted to integrate the common simulator types. For example, the National Chiao Tung University Network Simulator NCTUns (Wang and Lin, 2010) the Vehicles in Network Simulation (Sommer et al., 2011), and the V2X Simulation Runtime Infrastructure, VSimRTI (Schünemann, 2011) are recent examples of "composite" simulators that achieve bi-directional coupling (between TS and NS). Likewise, (Maroto et al., 2006) and (Olastam et al., 2008) each proposed a framework in which a driving simulator was surrounded by micro- and mesoscopic traffic simulation regions. In a similar effort, (Yan et al., 2008) investigated the credibility of a driving/traffic simulator to address safety issues at a single signalized intersection. Simulation outputs were compared with the field counts in terms of traveling speed and incident occurrences. Finally, (Punzo and Ciuffo, 2011) emphasized the four main requirements for appropriately integrated simulation models, which largely inspired the need for the current effort: *(1) accurate road matching between traffic and driving simulators; (2) synchronization of traffic and driving modules with real time; (3) consistency of the updating calculation frequency; and (4) management of autonomous vehicle visualization.*

With this background in hand, in the next section, we present a number of suggestions for how the research presented here can be expanded for other purposes, which serve as the Broader Impacts of the current work.

BROADER IMPACTS

Ultimately, the validated/integrated simulation environment described in this paper helps to broaden the range of applications for which transportation-based simulation can be applicable:

- **Clinical and Training Applications**. Driving simulators have been used for interventions for "vulnerable" sectors of our population (e.g., inexperienced teenage drivers, older drivers with cognitive impairment (Hulme and Thorpe, 2013), drivers with Attention Deficit and Hyperactivity Disorder (ADHD) (Fabiano et al., 2011)). As a result, a validated driving simulator with integrated intelligent traffic (and authentic driver behavior) could greatly improve the authenticity and overall quality of the artificial driving environment.
- **"Green" Studies in Transportation Science**. How do we design a 21st Century transportation environment to be safer and more efficient, while training tomorrow's drivers, pilots, and ship captains as transportation technology and innovation continues to evolve? These high-stakes questions require advanced and integrated M&S test environments to provide actionable and sustainable solutions. For example, with a reliable integrated simulation capacity, researchers could more accurately study the anticipated impacts of driving on "green" (environmental) concerns such as estimated vehicle mileage efficiency and predicted tailpipe emissions.
- **Future Transportation Planning**. Next-generation transportation environments may be capable of communicating with other vehicles and with the traffic infrastructure (e.g., RITA, 2014). Accordingly, an authentic simulation environment is required to fine-tune such a protocol, especially with the many Human Factors concerns involved for successful implementation.
- **Military Ground Vehicle Simulation**
  The applicability of these technologies can be expanded beyond civilian transportation. With an increasing prevalence of unmanned vehicles in mission-critical military applications, there is increasing need for complex (i.e., some are manned, and others are partially and fully autonomous). A recent example is Oshkosh's Mine Sweeping vehicles, whereby an M-ATV outfitted with a mine roller could lead a convoy of autonomous vehicles through hostile territory while putting a minimum number of troops at risk (Gastelu, 2014). Prior to technology deployment, it will be essential to analyze the associated human factors using advanced simulation.

In the next section, we outline the primary hardware components that have been employed for our test procedures.

DATA COLLECTION HARDWARE

Simulation Hardware

In the current study, a motion-based simulator has been implemented that consists of a six degree-of-freedom electrically actuated motion platform. Two passengers are accommodated in a front-seat vehicle passenger cabin. The driver supplies inputs to the simulator using a steering wheel (force feedback, with a 900˚ 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. Refer to Figure 1.

Figure 1 – Motion Simulator

Figure 2 – Vehicle Data

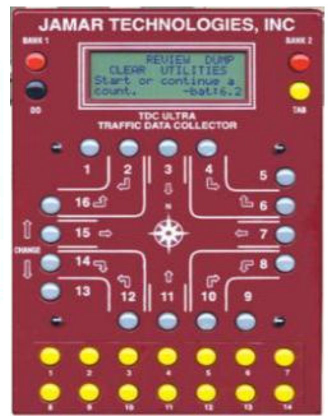


Figure 3 – Traffic Data

Validation Hardware

In an effort to validate our virtual driving environment, each subject driver in our pilot cohort drives the physical roads (i.e., after which our virtual model was developed), in an actual vehicle, under analogous conditions. Car Chip Pro (Davis Instruments, 2012) is a driving and engine performance monitor that is plugged in to the on-board diagnostics (OBD-II) port. See Figure 2. A driver operates the vehicle normally, and then data from the Chip (e.g., time stamp, distance traveled, speed, instances of extreme acceleration and braking) can be downloaded to a PC. As an auxiliary location tracker, a low-cost GPS receiver was also used to complement the Car Chip Pro data, and provided: timestamp, location information, and GPS (absolute position) traces at an update frequency of 1 Hz.

A hand-held Traffic Data Collector (TDC) (JT, 2010) was used for generating accurate traffic counts for our virtual simulation environment. Refer to Figure 3. The buttons are intuitively arranged to simulate a standard intersection, with 12 normally used for the left, go-through, and right movements from each of the four approach directions. At the end of every time interval, the data is automatically stored. For the purposes of our environment (described in the next section), we had 12 intersection counts, each taken at the same time of day (i.e., "rush hour", from between 3pm and 5 pm EST), all collected over a 2-week period, in 15 minute intervals (and multiplied by four to attain an hourly estimate). Each intersection count was performed twice, and averaged. Traffic signal timings (i.e., time green, yellow, red, in seconds) were attained for these same intersections with a stopwatch. Again, multiple timings were used for each traffic signal (during the same time of day), and averaged, to account for any data inaccuracies.

SIMULATION ENVIRONMENT DESCRIPTION

Driving Simulator (DS)

Once received by the driving simulation client, the user inputs to the simulator (i.e., steering, gas, brake) subsequently serve as input to the vehicle dynamics module (VDM) (Milliken and Whitcomb, 1956). The state outputs for the VDM include: vehicle position and orientation, velocities (current, maximum, and average), accelerations, tire forces, and tire operating conditions, which are then used to update the states of the motion system (i.e., haptic cues), the sound system (i.e., aural cues), and the graphics system (i.e., visual cues). For motion processing, the vehicle states are converted into DOFs (roll, pitch, yaw, heave, surge, and sway). For audio rendering, OpenAL is implemented, including: vehicle ignition, engine tone (which varies according to vehicle speed/RPMs), squealing tires (which vary in accordance with calculated slip angles), hazard/danger cues, and vehicle shutdown. Lastly, for visual feedback, the scene graphics are rendered using OpenGL, a 3-D graphics API, and include: the position/orientation of the human driven vehicle and the traffic vehicles (including visual cues for brake lights and turn signals), the roadway geometry, environment details (e.g., buildings and houses), traffic signage (e.g., street signs and speed limit signs), and traffic signals at intersections.

Traffic Simulator (TS)
For modeling the traffic macroscopically, the PARAMICS (v6.0) suite was selected for this research study, and 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. *Processor* allows multiple simulations for testing various configurations or alternative situations. Finally, *Analyzer* provides various tools to review several measures of effectiveness such as vehicle counts, speed, delay, travel time, and queues. The primary reason for selecting PARAMICS for this study is the fact that it has an add-on module called *Programmer* that 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 traffic and driving simulations together.

Integrated Simulator (TS-DS)
In the process of integrating the TS and DS environments, a number of design challenges were encountered:

- Graphics Rendering. The scene graphics rendering takes place on the DS side, which is contrary to how we proceeded in our initial pilot study (Hulme et al., 2010). This transition enabled multi-screen, wide field-of-view graphics, increased frame rate (from 30 to 60 Hertz), and custom graphics object design.
- TS Vehicle Behavior. To achieve smooth behavior of the traffic vehicles, path interpolation was employed. Because the TS operates (maximally) at 30 Hz., and the DS at 60 Hz., every other frame of data, for each traffic vehicle, had to be extrapolated based on the most recently received data points. This simple measure was effective at increasing vehicle smoothness and decreasing the motion "flutter" that was previously observed.
- DS Control Fidelity. In our pilot study, heading control of the subject vehicle acted less as a true steering capacity, and more as a binary, lane-changing feature – a limitation on typical traffic vehicle navigation inside of the TS. Anchoring the graphics rendering on the DS side afforded us the freedom to operate the subject vehicle with a smooth steering mechanism, and allowed for a more fluid motion of the adjacent traffic vehicles.

In the next section, we present details regarding our validation study that made use of our newly-developed and enhanced integrated simulation capability.

VALIDATION STUDY BACKGROUND

Participants were asked to drive a simulated course, all during comparable levels of traffic congestion and time of day. Participants were asked to drive a 3 mile path along a virtual depiction of New York State routes #62 (Bailey Avenue) and #263 (Millersport Highway). The excursion begins (on the South side) at Winspear Avenue, and concludes (on the North side) at just beyond the intersection of New York State route #324 (Sheridan Drive) and Millersport Highway. Along the way, the driver encounters 12 signalized intersections. Refer to Figure 4. The South intersection is shown in green, the North intersection is shown in red, and the 10 intermediate intersections are shown in yellow. The speed limits range from 30, to 35, to 40 mph throughout the excursion, as shown. In an effort to authenticate the pilot driving environment, major structures and landmarks have been modeled, along with road signs and vegetation. Refer to Figures 5 and 6. The former illustrates a Google Maps image of the chosen excursion, and the latter displays a screen capture of the software driving environment, shown driver point-of-view.

For all participants, the simulation excursion takes place (per the field data that was collected) at a similar time of day (e.g., "weekday, 4 pm") at a comparable level of pre-programmed traffic (e.g., "rush-hour, heavy"). Our approach to analyze traffic flow was primarily based on empirical analysis - observation and mathematical curve fitting models, as referenced by the Highway Capacity Manual (TRB, 2000). This source recommends modeling traffic flows using the whole travel time across a link using a delay/flow function, including the effects of queuing. Various data are collected and logged within the integrated simulation framework, including: timestamp, (lane) position, velocity, and various forces and accelerations on the virtual vehicle.

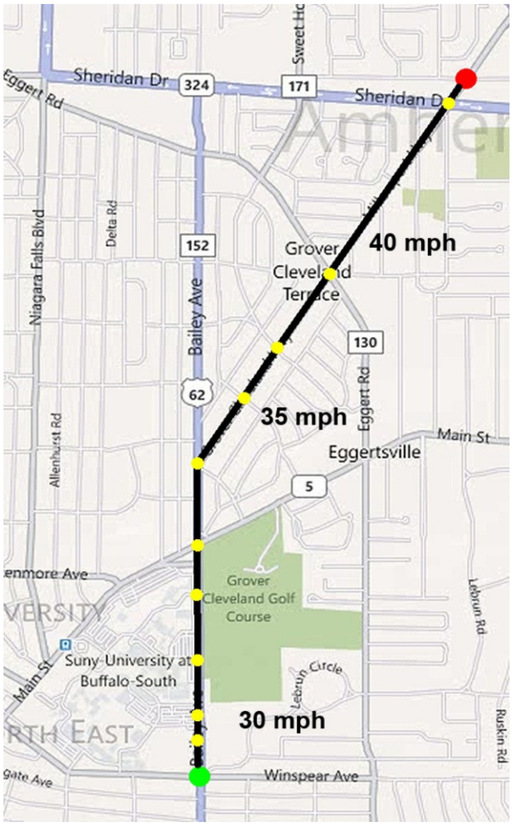


Figure 4 – Excursion Map

Figure 5 – Bailey Avenue (physical)

Figure 6 – Bailey Avenue (virtual)

For this study, 15 participants were recruited, 11 males and 4 females, ranging in age from 21 to 39 years, with an average age of 26.1 years. All participants were graduate students or staff members from the University at Buffalo, and had a minimum of 2 years driving experience. All of the participants were required to perform both components of the experiment: Field Test, and Simulator Test.

VALIDATION STUDY: RESULTS AND DISCUSSION

For the present research study, the performance evaluation compared numerous aspects of driver behavior between the real-world and the simulator, including the average corridor-level travel time for all drivers (from Point A to Point B), and the acceleration and deceleration profiles of individual drivers. Note: the sample size is listed as “30”, as each of the 15 drivers performed the excursions twice. The results are summarized below.

Average Travel Time

As can be seen from Table 1, the average total trip travel time in the simulator and the field are relatively close to one another. Hypothesis testing was conducted both for the southbound and northbound directions separately, with the null hypothesis being that the mean travel time in the simulation test equaled the mean travel time in the field. An unpaired two sample t-test confirmed that the population mean of the simulation travel time is not statistically different from the population mean in the field, at a significance level of 0.01 and 0.05, for excursions to the south and north ends, respectively.

While the differences were small, the travel time in the simulator was consistently slightly shorter than that observed in the physical road test. This is likely due to the fact that the perception of risk in the simulator is naturally lower than that on the physical road, and as confirmed by previous studies (e.g., Bella, 2008, and Törnros, 1998). Moreover, it can be observed that the travel time from the north to the south end was slightly larger than from the south to north, and both the physical road test and the simulator test exhibited the same trend. This is likely due to different signalization and traffic conditions in each direction.

Table 1 – Validation Study – Travel Time Statistics

a) Travel from North to South End				b) Travel from South to North End			
	Sample Size	*Mean (sec.)*	*Std. Dev. (sec.)*		*Sample Size*	*Mean (sec.)*	*Std. Dev. (sec.)*
Road	30	527.7	60.6	**Road**	30	480.0	52.7
Simulation	30	484.3	65.6	**Simulation**	30	461.2	50.0

Average Acceleration and Deceleration

To compare the driving behavior of individual participants, the acceleration and deceleration profiles are derived from both simulation and road test. Specifically, for each trace, we first intersect the segments with travel speed of between 0 and 35 mph (e.g., where the posted speed limit is 45 mph). After all traces are processed, we have four profiles for each driver (i.e., accelerations and decelerations in simulator, and their road test counterparts). Given that the speed in these profiles is fixed to 0-35 mph, we use time as the measurement for comparison. Figure 7 shows the acceleration and deceleration time between simulation and road test.

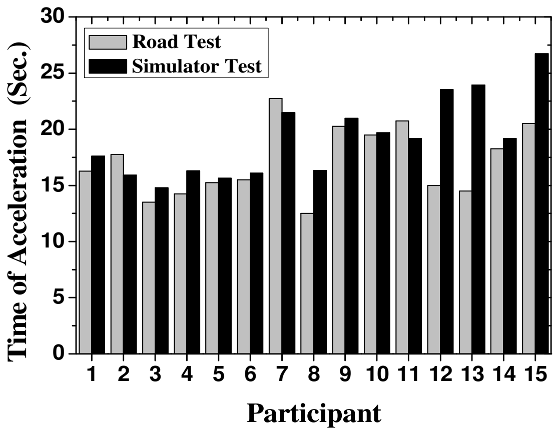


Figure 7 – Acceleration Comparison

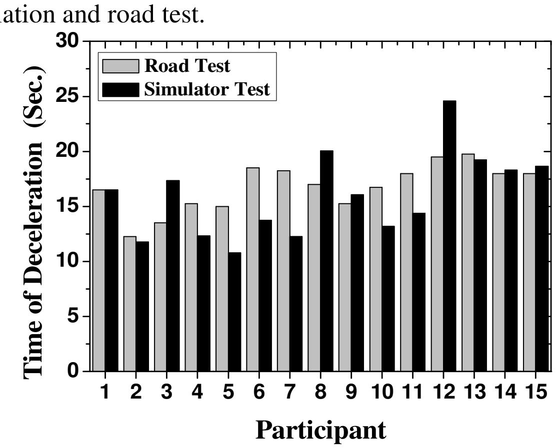


Figure 8 – Deceleration Comparison

Average acceleration and deceleration are "comparable" between road test and simulator test. It is interesting to note that *most* (12 out of 15) participants accelerate slower in the simulator (i.e., a longer simulation acceleration duration in Figure 7), and of those profiles that are approximately equal (Profiles: 1, 2, 9, 13, 14, 15), *most* (6 out of the remaining 9) decelerate faster in the simulator (i.e., a shorter simulation deceleration duration in Figure 8). This seems to indicate that people are more cautious when getting up to speed, but tend to be more abrupt when slowing down in the simulator. A longer practice session before the test (i.e., more acclimation), and better calibration of simulator dynamics (and proper attainment of brake pedal "feel" – a common complaint in many artificial driving environments) may help to reduce these discrepancies.

HUMAN FACTORS STUDY BACKGROUND

Motivation

Autonomous vehicles are the future of driving - from obeying traffic signals, to detecting pedestrians, to route selection. Most current research focuses on technical advances, yet human factors have often been overlooked, and are particularly challenging when considering the incremental development of vehicular autonomy (i.e., both human-driven and autonomous vehicles will, for some period of time, share the road). Many critical questions have not yet been answered: a) how people feel about "driving" autonomous vehicles, b) how will autonomous vehicles influence traffic patterns, and c) how will autonomous vehicles interact with traditional vehicles? In this paper, we use our integrated simulator to analyze human factors challenges associated with autonomous vehicle technologies. Specifically, we present a pilot study that analyzes a simulated Autonomous Speed Control System (ASCS).

Experimental Design

In this experiment, 30 participants were recruited, 15 males and 15 females with an average age of 26.7 years (SD = 2.5) and an average annual driving mileage of 5,300 miles (SD = 2,185). Each participant was paid $20 to complete the experiment. Three different traffic flow speeds (25 mph, 45 mph and 65 mph) were evaluated which correspond to residential, rural, and highway driving conditions. The experiment was further divided into two components:

- **Both vehicle headway and speed were assigned by the simulator**. Participants were directed not to override the control. The vehicle was programmed to autonomously follow the leading vehicle according to the headway assigned by the ASCS. The speed of the traffic flow was configured in the TS component of the integrated simulator. At a given speed, three headways were evaluated (0.5s, 1s and 1.5s), and participants were asked to observe the driving for two minutes, and then provide their assessment by responding to a questionnaire.
- **The subjects were given control of the ASCS**. The headway could be adjusted through buttons on the driver's dashboard, in a manner similar to a common cruise control system. The initial headway was set to 1.5s for all trials. Similar to the settings in the first component, the vehicle would adjust its headway according to the driver's control, and eventually follow the flow speed of traffic. The process of adjusting the headway was captured by the simulator trace file, and we imposed no time limit for participants to assign their headway. Since participants were informed to choose the minimum headway they would accept, we refer to the final headway as the "minimum headway", and the final distance to leading vehicle as the "minimum distance".

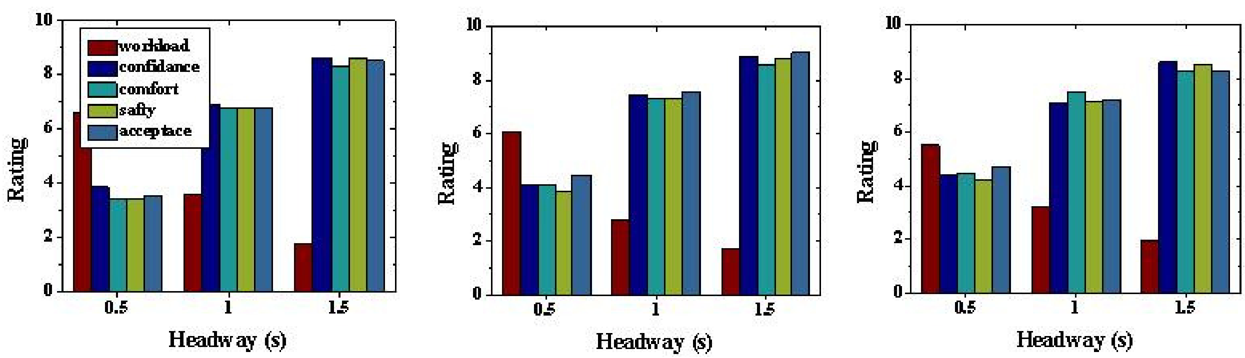
Overall, each participant was involved in 12 total trials (i.e., nine trials for the fixed speed-headway condition, and three trials to manually assign the headway). Five measures describing the driver's ASCS were evaluated in the questionnaire: **1) Workload when the vehicle was controlled by the ASCS, 2) Confidence in the ASCS not leading to a collision, 3) Comfort level, 4) Safety level, and 5) Overall acceptance**.

HUMAN FACTORS STUDY: RESULTS AND DISCUSSION

In this section, we describe the result from the ASCS study. First, we present the descriptive statistics of the responses noted from the questionnaire and data collected from the simulator output. Then, we investigate the correlation between the minimum headway and the driver's responses.

Descriptive Analysis

Descriptive statistics (i.e., means and standard deviations) on dependent variables (i.e., workload, confidence, comfort, safety and acceptance) were provided to describe each test subject's opinion on the ASCS, and the participant's minimum headway and distance when they were driving with the ASCS. Refer to Figure 9.



25 mph **45 mph** **65 mph**

Figure 9 – The Mean Values of the Five Dependent Variables

As expected, we observed that a longer headway leads to a higher participant rating on confidence, comfort, safety and acceptance, and reduced driver workload with ASCS. At different speed levels, the ratings are relatively consistent. This shows that drivers will easily accept the use of ASCS, thanks to the prevalent use of traditional cruise control systems. Analysis of variance (ANOVA) indicates that subjective opinion of the ASCS is significantly affected by the headway. For a detailed report on the influence of gender and driver experience on the results, please refer to (Hou et al., 2014).

Figures 10 and 11 display the average minimum headway and minimum distance to the leading vehicle, respectively. The headway time (Figure 10) assigned by the participants remains relatively stable, ranging between 1.12 and 1.26 seconds for all three scenarios. On the other hand, distances (Figure 11) ranged from 51 to 113 feet, based on the speed of travel. Generally speaking, the results suggest that higher driving speed will generate longer minimum distance to the leading vehicle. However, the effect of speed on minimum headway is not clear. This may indicate that most drivers prefer to maintain spacing between vehicles relying on their judgment on distance, and that their judgment on headway (time) is less reliable. The significant difference of the minimum headway when the driving speed was 25 mph may also stem from each participant's lack of experience of (or need for) cruise control in a residential environment.

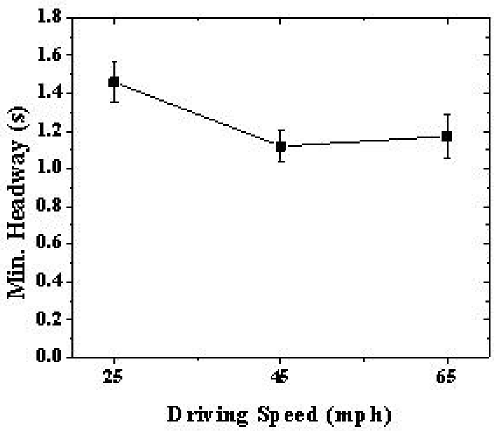


Figure 10 - Effect of speed on minimum headway

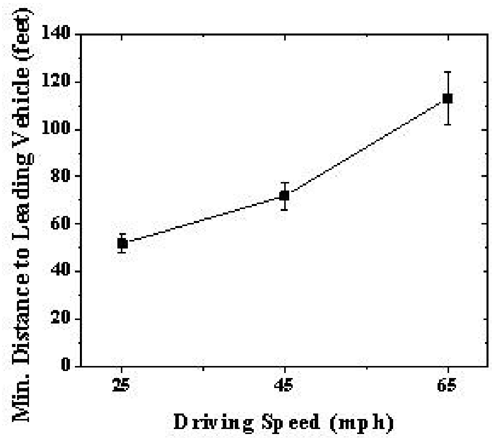


Figure 11 - Effect of speed on minimum distance

Correlational Analysis

In this sub-section, we are interested in the correlation between minimum headway settings and participant responses noted in the questionnaire. The correlation between minimum headway, minimum distance, and the driver's opinion of the system was conducted first. Considering that the correlation coefficients may have been inflated by gender, driving experience and driving speed, partial coefficients were calculated. Refer to Table 2.

Table 2 - Partial correlation matrix between minimum headway, minimum distance and driver opinion

Headway=0.5s	**Workload**	**Confidence**	**Comfort**	**Safety**	**Acceptance**
Minimum headway	0.283**	-0.387**	-0.245*	-0.271*	-0.241*
Minimum distance	0.232*	-0.364**	-0.245*	-0.273*	-0.273*
Headway=1.0s					
Minimum headway	0.483**	-0.672**	-0.561**	-0.648**	-0.631**
Minimum distance	0.422**	-0.599**	-0.510**	-0.584**	-0.578**
Headway=1.5s					
Minimum headway	0.478**	-0.509**	-0.480**	-0.552**	-0.484**
Minimum distance	0.439**	-0.459**	-0.422**	-0.486**	-0.435**

***Note:* *$p < 0.05$; **$p < 0.01$**

Significant and positive correlation exists between headway and workload, and negative correlation exists between headway and other measurements. This result confirms that headway and inter-vehicle distance are the dominant factors on driver acceptance with ASCS. With a headway of 1.0s, the minimum headway and minimum distance associated with the driver's opinion (i.e., on workload, confidence, comfort, safety and acceptance) shared higher partial correlations with one another when compared to headways of 0.5s and 1.5s. This observation is in accordance with our "calculated" minimum headway, earlier reported as ranging between 1.12-1.26s.

CONCLUSIONS

This paper has summarized our efforts in developing an integrated traffic and driving simulation framework. Following successful implementation, the integrated simulator was validated through a comparison study that compared various aspects of driver behavior in the simulator environment to their behavior while driving in the real-world, after which the former was modeled. The proposed integrated traffic and driving simulator system was found to be capable of accomplishing the intended two way communication between the traffic and the driving simulator. Furthermore, the methods used in this study to overcome the integration challenges appear to have allowed for a high-fidelity simulation environment that closely resembled reality and hence resulted in driving behavior close to that observed in the field. The travel time in the virtual environment was observed to be comparable to the field test, although the road test travel time was slightly higher. As well, the acceleration and deceleration profiles recorded in the simulation platform compared favorably to those observed during the field test.

The current study further investigated driver acceptance on a simulated Autonomous Speed Control System (ASCS), and provided recommendations for reference values for a "minimal headway" based exclusively on a driver's perception of tolerance. An average minimum headway ranging between 1.12 – 1.26s was found in this study, depending on the speed of travel, which ranged from 25 to 65 mph. In contrast, higher speeds resulted in longer spacing between vehicles, with distances of 51 to 113 feet observed. This perhaps indicates that driver perception of headway is inconsistent, and that judgment of headway relies primarily on the spacing between vehicles (rather than time). In analyzing the correlation between assigned headway settings (on the simulator) and participant responses (on the questionnaire), it was found that positive correlation exists between headway and workload, and negative correlation exists between headway and other measurements. This result confirms that headway and inter-vehicle distance are the dominant factors on driver acceptance with ASCS.

Ultimately, as ground vehicle crash avoidance technologies continue to evolve, the design of transportation modes and systems, the evaluation of efficient transportation behaviors, and the subsequent insurance of the safety of individuals engaging with the system are critical technological and public health matters. As such, the research presented in this paper has served as a vital step towards broadening the range of applications (e.g., training, clinical, transportation and human factors research) for which transportation-based simulation can be applied.

FUTURE AND ONGOING WORK

The integration framework presented in this paper is an evolutionary work in progress. There are numerous potential avenues for its extensibility and expansion, and these are summarized here:

Simulator Integration that includes Network Simulation

The TS-DS integration is the first step towards the development of a more complete simulator integration for transportation research. In development is an integration that includes a link to a Network Simulation (NS) that is capable of communicating with other vehicles and the traffic infrastructure, and is also capable of sending warning messages to the driver. Refer to Figure 12, which illustrates the 3-in-1 Integrated Traffic-Driving-Network Simulator (ITDNS) (e.g., Zhao et al., 2012).

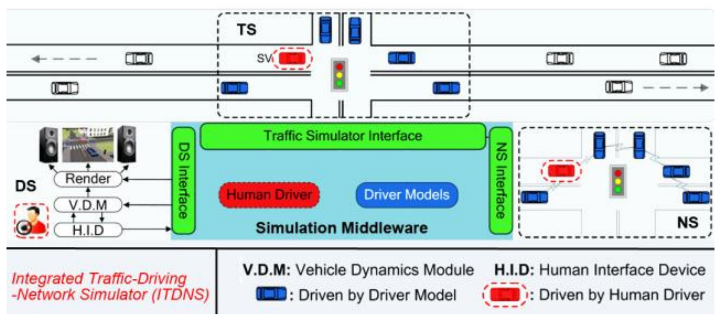


Figure 12 – ITDNS (3-in-1 simulator)

Multi-participant networked vehicle simulation

When analyzing the real-time impact of driver decisions based upon the actions of others (e.g. a driver swerving into another lane), it is useful to allow simulation participants to interact in real-time with other human participants located within the same environment. Borrowing heavily from multi-player video game approaches, in development is a server-client architecture that allows multiple driving simulators to be linked across a network. Each client executes a common instance of the integrated DS/TS environment on a local computer. All simulation-relevant information to be exchanged between participants (clients) is then updated through the Server, using TCP/UDP.

Analysis of Human Factors and Driver Behavior

A common design objective of an in-vehicle notification system 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 is whether it is efficient to rely on human response to, for example, 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 a "hybrid" situation: **both** human-driven vehicles and autonomous vehicles, which is the natural deployment path of this technology.

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