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An integrated traffic-driving simulation framework: Design, implementation, and validation

Yunfei Hou [a,*], Yunjie Zhao [b], Kevin F. Hulme [c], Shan Huang [b,1], Yaqin Yang [c,2], Adel W. Sadek [b], Chunming Qiao [a]

[a] Laboratory for Advanced Networking Design, Evaluation and Research (LANDER), Department of Computer Science, University at Buffalo, Buffalo, NY 14260, USA
[b] Transportation Systems Engineering Laboratory (TSEL), Department of Civil and Environmental Engineering, University at Buffalo, Buffalo, NY 14260, USA
[c] New York State Center for Engineering Design and Industrial Innovation (NYSCEDII), University at Buffalo, Buffalo, NY 14260-1810, USA

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A B S T R A C T

This paper first describes the process of integrating two distinct transportation simulation platforms, Traffic Simulation models and Driving Simulators, so as to broaden the range of applications for which either type of simulator is applicable. To integrate the two distinct simulation platforms, several technical challenges needed to be overcome including reconciling differences in update frequency, coordinate systems, and the fidelity levels of the vehicle dynamics models and graphical rendering requirements of the two simulators. Following the successful integration, the integrated simulator was validated by having several human subjects drive a 2.5 mile long segment of a signalized arterial in both the virtual environment of the integrated simulator, and in the real-world during the evening "rush hour". Several aspects of driving behavior were then compared between the human subjects' driving in the "virtual" and the real world. The comparisons revealed generally similar behavior, in terms of average corridor-level travel time, deceleration/acceleration patterns, lane-changing behavior, as well as energy consumption and emissions production. The paper concludes by suggesting possible extensions of the developed prototype which the researchers are currently pursuing, including integration with a computer networking simulator, to facilitate Connected Vehicle (CV) and Vehicle Ad-hoc Network (VANET) related studies, and a multiple participant component that allows several human drivers to interact simultaneously within the integrated simulator.

1. Introduction

The transportation community has for long used two distinct types of simulator types, but with no true integration. On one hand, the community used microscopic Traffic Simulation (TS) models for evaluating the system performance of transportation networks from an *operational* standpoint (Transportation Research Board, 2000), and on the other, it used Driving Simulators (DS) for evaluating the response of individual human subjects within a virtual in order to study various aspects related to driver behavior, human factors and safety evaluations.

* Corresponding author. Tel.: +1 716 263 8613.
E-mail addresses: yunfeiho@buffalo.edu (Y. Hou), yunjiezh@buffalo.edu (Y. Zhao), hulme@buffalo.edu (K.F. Hulme), asadek@buffalo.edu (A.W. Sadek), qiao@computer.org (C. Qiao).
[1] Present address: Terra Technology, 1515 East Woodfield Road, Schaumburg, IL 60173, USA.
[2] Present address: Bloomberg LP, 731 Lexington Ave, New York, NY 10022, USA.

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Each simulator type, when used independently, has its own set of limitations. While TS models allow for capturing the dynamics of full-scale traffic networks, they lack driver behavioral realism, since vehicle movements are based on idealistic car-following models that are often simplifications of reality. This limits the application of traffic simulators to the analysis of the transportation system mainly from an operational efficiency standpoint, and pays little regard to safety considerations. Archer (2000), for example, noted that 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 (Saccomanno and Cunto, 2006). Moreover, because human driving behavior is not modeled in detail in TS, it is insufficient to evaluate the effectiveness of eco-driving strategies and applications, which have received increased attention recently and which attempt to encourage drivers to change their driving behavior (e.g., the way they accelerate or decelerate) so to conserve energy.

DS, on the other hand, allow for studying driver behavior by immersing human subjects within a virtual simulation environment and monitoring their reactions. Unfortunately, however, DS often lack traffic authenticity and transportation network realism, since in the majority of DSs, accompanying traffic is often pre-programmed and does not react according to the real-time actions of the human subject who is operating the human-driven vehicle. Moreover, the lack of transportation network realism of many driving simulators limits their application to a small subset of vehicle scenarios (e.g. a single roadway intersection) versus transportation system-level evaluations.

An interesting concept that has emerged over the last decade is the prospect of integrating microscopic traffic simulation and driving simulators (see Section 2.1 for more details). The TS environment provides a realistic representation of the transportation network and the prevailing traffic conditions (e.g., congestion levels, availability of gaps, speeds, and intersection queues), beyond what is currently possible using a standalone DS. Simultaneously, input from the driving simulation provides for authentic driver behavior, which is particularly important for understanding the impact of individual driver behavior on system-level performance. While such a concept has been proposed for several years now, there are still several issues that need to be resolved to provide a complete and accurate integration. Moreover, because integration attempts are relatively recent and largely exploratory in nature, there appears to have been very limited focus on *validating* the resulting integrated simulator. The term "Validation" used in this context refers to the process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses of the model or simulation (e.g., Balci, 1998).

The current paper contributes to this emerging area of research, by first describing a successful integration of these two heterogeneous simulation platforms and how the challenges encountered were overcome; the result is *a prototype system that allows a human participant to drive a subject vehicle within the virtual driving simulation environment amidst traffic from the microscopic traffic simulation*, *which intelligently responds to the actions made by the human driver*. Following this, the paper describes an exploratory research study aimed at validating the integrated TS–DS platform by comparing the performance of human subjects both within the virtual environment of the integrated simulator as well as in the real-world. The contribution of the current paper is therefore twofold: (1) describing the authors' research on overcoming the challenges of integrating TS and DS; and (2) describing a procedure for the validation of the resulting simulator, and proposing a number of metrics or performance measures for assessing validity.

The paper is organized as follows. Section two provides a brief overview of previous attempts at integrating traffic and driving simulators. The section also cites some examples of previous studies aimed at validating and calibrating *stand-alone* TS models, on one hand, and *stand-alone* DS on the other. Section three describes the main components making up the integrated simulator developed in this study. Note that in addition to the two main components, namely the TS and DS, the integrated simulation framework developed herein includes a detailed emissions model to allow for evaluating green and eco-driving applications. Section four discusses the integration and the validation methodologies. The results from the validation study are then presented in section five. The paper concludes by summarizing the main conclusions derived from the study and describing the authors' future plans for further developments and enhancements to the integrated simulation framework.

2. Literature review

2.1. Integrated traffic/driving simulation

In recent years, there have been a handful of attempts aimed at integrating TS and DS, including previous and ongoing work by the current research team (e.g., Hulme et al., 2010; Zhao et al., 2012). A sampling of the most relevant of those studies is presented here, chronologically.

Jin and Lam (2003) carried out a study on driving behavior with a preliminary integrated traffic and driving simulator. The integration utilized route choices dictated by Variable Message Signs (VMS), however, no validation of the integrated framework was described in the paper (it was just mentioned as a recommendation for future research). Maroto et al. (2006) proposed a micro-simulation model with a user-driven vehicle surrounded by simulated traffic – referred to as the "control zone". The authors proposed two layers to address the surrounding traffic: (1) driver model and (2) vehicle model, respectively. As part of the validation/analysis, the root mean square error (RMSE) of simulation speed versus speeds encountered during the field test was observed.