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Integration of a driving simulator and a traffic simulator case study: Exploring drivers' behavior in response to variable message signs☆

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ABSTRACT

For the first time, a driving simulator has been integrated with a traffic simulator at the network level to allow subjects to drive in a fairly realistic environment with a realistic traffic flow and density. A 10 mi^2 (25 km^2) network was developed in a driving simulator and then exported to a traffic simulator. About 30 subjects drove the simulator under different traffic and driving conditions and variable message sign (VMS) information, both with and without integration. Route guidance was available for the subjects. The challenges of the integration process are explained and its advantages investigated. The study concluded that traffic density, VMS reliability and compliance behavior are higher when driving and traffic simulators are integrated. To find factors affecting route diversion, researchers applied a binary logistic regression model. The results indicated that the original chosen route, displayed VMS information, subjects' attitude toward VMS information helpfulness, and their level of exposure to VMS affect route diversion. In addition, a multinomial logistic regression model was employed to investigate important factors in route choice. The results revealed that there is a significant correlation with driver route choice behavior and their actual travel time, the need for GPS, VMS exposure and also the designed scenarios. It should be noted that the paper was peer-reviewed by TRB and presented at the TRB Annual Meeting, Washington, D.C., January 2016.

1. Background

By providing applicable real-time information, an advanced traveler information system (ATIS) has the potential to influence driver behavior [1]. ATIS information would be helpful to drivers only when they feel that they do not have sufficient knowledge to make the right choice [2]. That said, two individuals with the same knowledge but different decision approaches could have distinctly different perceptions about their lack of knowledge [3]. An increasingly common public or non-personalized information device is the variable message sign (VMS) that provides quick information to drivers about adverse road conditions, traffic incidents, travel time, speed control, managed lanes, traffic regulations, road construction, etc. The key factor that ensures a VMS's effectiveness is the level of drivers' response to the displayed information with the lowest distractive impact. More traffic information provision in an effective way leads to better route choices and, therefore, a less congested network [4–7].

To obtain a better understanding of driver behaviors, laboratory experiments have been recommended and tested during different studies in a limited capacity and have been proven to be an effective and practical approach [8]. Since the beginning of the 20th century, many traffic flow models have been applied for description, simulation and prediction of traffic [9]. With the development of digital computers in 1952, a few researchers simulated individual intersections and short sections of freeways [10]. Following the first simulation program presented by Harry H. Good [11], in the '60s, the attempts of the Washington, D.C., District Department of Traffic (DCDOT) to evaluate the proposed signal timing led to the development of a network simulation model, called TRANS [12]. In the following decades, researchers have proposed various simulation models such as UTCS-1, which is used to simulate bus operation [13]; TEXAS, to evaluate safety features of individual intersections [14]; also the INTEGRATION mesoscopic simulation model [15]; CORSIM, which was the result of the urban NETSIM and freeway FERSIM microscopic models [16]; TRANSIMS [17]; HUTSIM [18]; DYNASMART [19]; NGSIM [20]; VISSIM [21]; PARAMICS [22]; and AIMSUN [23].

A driving simulator (DS) provides a realistic simulated setting by enabling users to drive in a virtual highway system. Transportation researchers have been using the evolving DS technology since the '60s

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[24] to investigate driver-controlled behavior in various conditions such as normal, fatigued, and drug-impaired. A comprehensive view of route choice behavior cannot be captured in any experiment but the DS. In a DS, unlike other methods, alternative routes are revealed when a driver chooses a route, and full information about all possible routes is available. In addition, the use of various information provisions and controlled traffic and environmental scenarios is not possible with the other methods. Furthermore, drivers as test subjects are not likely to experience the same events and conditions. Therefore, simulation appears to be the best way to study route choice behavior.

A realistic representation of traffic conditions is a prerequisite to study the effect of travel information on driver behavior [25]. The results of the studies using driving simulators often depend on the traffic conditions and their composition [26]. Driving simulators have improved considerably over the years and many of them are able to generate traffic around the driver's vehicle. However, there is still a shortcoming in their traffic patterns — vehicle simulation is according to a deterministic model, which may not show realistic kinematics and vehicle interactions. This can substantially influence the results of behavioral studies such as route choice analysis in a DS environment. On the other hand, in a traffic simulator, the dynamic pattern of the traffic flow closely resembles the real pattern, considering all aspects of traffic engineering, such as ITS, adaptive traffic controls, and traffic management actions. Traffic simulation determines the effect of various infrastructures on traffic flow using observation and analytical techniques. To increase the realism of the surrounding traffic and retain control over traffic volume, a DS can be integrated with a traffic simulator (TS). Lane changing, gap acceptance, and overtaking behavior are some of the areas in which the TS has an advantage over the DS traffic generation pattern. Integrating a DS and TS causes the behavior of the surrounding vehicles to more closely resemble the real world. The integration allows subjects to drive in a simulator with a local traffic situation managed by a traffic model, while providing a realistic flow and density.

The different nature of DSs and TSs makes it difficult to integrate them. However, this integration is desperately needed in different areas of studying driver behavior and the human factors affecting transportation systems and road accidents. In DSs, drivers' reactions are observed but traffic patterns are not fully realistic; in TSs, traffic patterns are more realistic but one cannot take control of a vehicle as a subject, while an interrelationship between driver behavior and traffic flow exists. Although a TS is a useful tool to study traffic patterns, it is not possible to study and describe the behavior of an individual driver [27]. In the real world, traffic condition is affected by an individual's decision which itself depends on the density and flow rate. The behavior of the surrounding vehicles in a DS is a key element of ensuring a realistic environment. A deterministic model in DSs may be sufficient in some studies, but it can negatively affect the sense of the subjects driving in a virtual environment. They also may incorrectly predict the behavior of the surrounding vehicles, causing misleading results. Furthermore, some traffic scenarios may not be implemented with simplistic behavioral models [28].

Only a few studies have been conducted regarding the integration of a DS and TS, all of which limited their work to one or two road sections without any ramps or intersections. All attempts tackled many issues, the most important of which were road matching between the DS and TS, synchronizing driving and traffic simulators with real time, consistency of updating frequency, and the levels of detail in both environments [25,29,30].

Having exactly the same network in DS and TS software is not easily achieved, but it is possible if both platforms use a common description of road network and environment and both have the capability of importing network data [29]. DriveSafety — VISSIM [25], VTI Driving Simulator III — developed simulation model [28], WorldUp — Qparamics [27], and SCANeR 30 — AIMSUN [29,30] are driving simulator-traffic simulator pairs that were integrated.

This study provides a procedure to integrate a driving simulator — UC-win/Road — and a traffic simulator — S-PARAMICS.

A case study is conducted to investigate the drivers' reaction to VMS in an integrated environment as well as in the DS-only environment. Comparing the results of the two situations indicates the differences in driver behavior while exposing them to realistic patterns of adjacent traffic. Investigation of subjects' compliance rate and their consistency level in route choice behavior corresponds to integrated scenarios, revealing the advantages of a DS integrated environment. Furthermore, factors affecting route choice behavior are analyzed using a logistic regression model.

2. Methodology

In this research, a network-level integration of a traffic simulator (S-PARAMICS by SIAS) and a driving simulator (UC-win/Road by FORUM8) was conducted to take advantage of both graphical presentations and traffic flow theory in studying different aspects of driver behavior.

UC-Win/Road has the capability of generating traffic on the roads, and the subject's vehicle drives among other vehicles. However, the generated traffic does not fully follow traffic flow theory. For example, the vehicles do not change their lane automatically, unless the user manually defines a lane-changing spot. The integration would import surrounding traffic flow from PARAMICS, which is stochastic and follows traffic flow theory, to UC-Win/Road.

A fairly small network of 25 km^2 (10 mi^2) from I-95 to downtown Baltimore was developed. The study area as well as the origin, destination, and three alternative routes from the origin to the destination are presented in Fig. 1. The alternative routes are exit 51 (Washington Blvd.), exit 52 (Russell St.), and exit 53 (MD-395). MD-395 is the major route to the destination. According to Google Maps, the distance via this route is 3.42 mi and in normal off-peak condition takes 6 min to reach the destination (downtown Baltimore). The distance via Russell Street is slightly less (3.3 mi) but takes 7 min. The Washington Blvd. route is the shortest in distance (3.11 mi) but the longest in travel time (12 min).

The aforementioned network was developed in both the DS and the TS. It was very challenging to create the exact same roads and traffic lights with the same signal timing in both simulators, requiring a massive amount of work because the definitions and visualizations of network elements are different in the two software packages.

In theory, one should be able to make the network with all road specifications, speed limits, and traffic lights; define origins and destinations; generate traffic and save vehicles' positions in the TS; then import the network to the DS, assign traffic lights to the intersections in the DS, and simulate the imported vehicles' movement. However, integration is much more complicated in practice. Different definitions of road segments, intersections, and ramps make it difficult to have the same network in both the DS and the TS. We created the network in the DS, exported it to the TS, and then performed a lot of trial and error in editing the network between the two software until the network was very similar in both the DS and the TS. Ramp definition was the major inconsistency, and we had to use intersections rather than ramps in the DS, since the TS does not have off-ramp capabilities and uses intersections instead. However, some TSs have off-ramp capability and the above problem may not occur when integrated with a DS. Graphical features of intersections and ramps are different in angle between two intersecting roads, slope of the roads, shoulders, guard rails, etc. Therefore, it was very challenging to use the intersection definition for ramps in the DS.

After the exported network was altered in the TS to be as similar as possible to the original network in the DS, traffic was generated on all roads in the TS. Then it was saved and imported to the DS to test the consistency between the networks in both software. Many editing iterations were needed to make the roads and intersections visually and functionally work the same in both software. The final network