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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

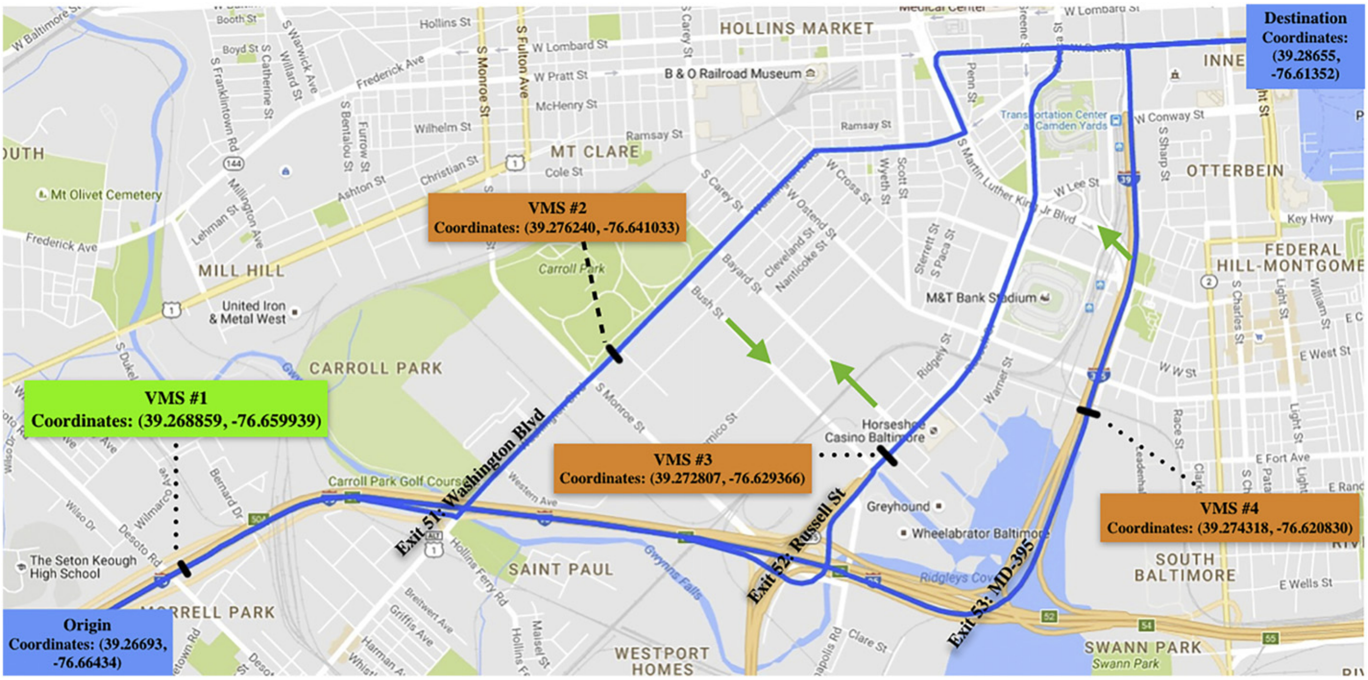

Fig. 1. Study map.

consisted of six ramps, 33intersections, 90 links, and seven bridges. Traffic lights were added to the network in the TS and timings were set accordingly. The generated traffic in the TS is imported into the DS and the subject drives among the traffic generated by the TS. A plugin of the DS controls the interaction between the generated traffic and the subjects' vehicle to make sure they don't collide. It is important to have the exact same network in both simulators since the generated traffic in the TS needs to be on the exact same road in the DS and not go off the road.

2.1. Scenario design

Six different scenarios were provided to evaluate route choice and diversion patterns. The scenarios are in three pairs of (D-1 and I-1), (D-2 and I-2), and (D-3 and I-3) for DS-only (D) and Integration (I). Four VMSs were added to different locations of the network, one of which included quantitative content and the others qualitative content. Fig. 1 illustrates the study map along with VMSs' locations. In the first scenario pair (D-1 and I-1), the quantitative VMS (VMS #1) located on I-95 one mile before the decision point is turned off to find out what route the subjects would take without information provision. The three qualitative VMSs (VMS #2, 3, 4) suggest taking the detour due to an accident to see if they will comply with the sign and reroute. Detour signs and personal route guidance (i.e., GPS) were provided to the subjects. Therefore, the subjects could follow the detour sign or use the GPS[1] to reroute from their current route. In the second pair of scenarios (D-2 and I-2), the quantitative VMS gives equal travel time (to the destination) of 8 min via MD-395 and Russell Street and 14 min via Washington Boulevard to find subjects' route choice when the two routes have equal travel time. The three qualitative VMSs were the same as the first scenario to find the diversion rate. The quantitative VMS in the third pair of scenarios (D-3 and I-3) stated that travel time on MD-395 is 12 min, on Russell Street 8 min, and on Washington Boulevard 14 min to determine the subjects' route choice when the main route (MD-395) is much more congested than the other routes. The three qualitative VMSs were turned off in D-3 and I-3 scenarios to find the diversion rate based only on the subjects' observation of traffic. The green arrows in Fig. 1 show the alternative routes that the subjects were able to switch to, after observing the qualitative VMS message and/or congestion in their current route. In all six scenarios, the subjects encountered accidents, lane closures, and congestion on primary routes while the suggested detours had free-flowing traffic.

Table 1 summarizes the aforementioned scenarios.

[1] Note that a research team used a limited simulated GPS not a real GPS. It shows on the screen where to go next. The observer was used as a guide as well to direct the subjects if they needed more guidance.

2.2. Traffic generation in the TS for I scenarios

To satisfy travel time, traffic volumes, and congestion levels required by the scenarios, 25 zones were defined and the origin-destination (OD) matrix was constructed for the network in the TS. Determined volumes in the OD table were assigned to the paths and lanes automatically.

Lane closures, defining low speeds for vehicles on accident corridors, and poor signalization (on Washington Boulevard) congested the routes. The result was saved as two different vehicle position files for two different travel time compositions of scenarios to be simulated in the DS.

2.3. Network preparation in the DS for I scenarios

The network in the DS was outfitted with the same speed limits, lane closures, and traffic lights with the same settings as the TS. Then, the traffic generator of the DS was disabled and traffic generated by the TS

Table 1
Summary of study scenarios.

Scenario	Message content	
	VMS #1 (quantitative)	VMSs #2, #3 and #4 (qualitative)
D-1 & I-1	–	Accident ahead take the detour
D-2 & I-2	Exit 51: 14 min Exit 52: 8 min Exit 53: 8 min	Accident ahead take the detour
D-3 & I-3	Exit 51: 14 min Exit 52: 8 min Exit 53: 12 min	–

was added to the Micro Simulation Player of the DS. The DS visualized the imported traffic in its own environment and made sure that it would not collide with the subject's vehicle. Therefore, the subjects drove among the traffic generated by the TS in the integration scenarios.

Since traffic lights in the DS were set with the same timing and offset as those in the TS, it was expected that the movement of the simulated cars be synchronized with signals, but the synchronization works only for very low traffic volumes. To have traffic movement synchronized with signals, a simulation of traffic lights without any vehicle on the network was saved and added to the Micro Simulation Player to be used instead of regular traffic lights. That meant signal timing would not be affected by traffic volume. The DS plug-in ran the two added simulations (vehicles and signals) and provided traffic synchronized with the traffic lights.

2.4. Network preparation in the DS for D scenarios

Traffic volume was assigned to the network furnished with traffic lights, lane closures, and speed limits similar to the ones in the TS. The first step in traffic assignment in the DS was specifying the number of vehicles for each road and each lane of the road (the default is an equal share for lanes). Generated vehicles in the DS would stick to the original lane and need to be moved to another lane manually if required. Furthermore, at each intersection, the percentages of the vehicles in each lane going in each direction needed to be specified.

Following traffic assignment in the TS, traffic was assigned to the network in the DS manually to have a fair comparison between integration and DS-only scenarios. The manual assignment was very time-consuming, requiring manual lane changing and specifying the percentage of traffic for each direction at each intersection. As the final step, roadside objects (vegetation, buildings, traffic signs, etc.) and VMSs were added to the network in the DS.

2.5. Survey questionnaires

Three survey questionnaires were provided, two of which were handed to the subjects. The first questionnaire gathered socio-economic data. The second questionnaire was specific to the study network. While representing a map similar to Fig. 1 (without showing the alternative routes from the origin to the destination), subjects were asked to draw on the map the primary route they would take to reach the destination from the origin. They were also asked about their familiarity with the area, route guidance frequency usage, and anticipated driving time from the origin to the destination. Furthermore, their willingness to change their route in the case of observing a VMS message of "ACCIDENT AHEAD TAKE THE DETOUR" was questioned. The third questionnaire that was filled out by the examiner inquired about subjects' experience, route taken, diversion, perceived travel time, and so on.

3. Results and discussion

3.1. Participants' characteristics and responses

Twenty-seven subjects drove a total of 148 scenarios, an average of 5.4 scenarios per person. The research team explained an overview of the study and asked participants to read and sign the consent form, explaining the risks associated with using the driving simulator. Next, the subjects practiced for a few minutes to get acquainted with driving the simulator, and then a scenario was randomly assigned to them to drive to avoid biasness of the behavior due to their past experience. They were asked to drive more scenarios after a short break, if they wished to do so. The number of scenarios to drive varies between one and six, depending on the subjects' willingness. Some people did not have time for more scenarios and others got a headache or became dizzy and did not wish to continue. Out of 27 subjects, 25 subjects completed more than or equal to 4 scenarios (Group I) and two drove fewer than 4 scenarios (Group II). Out of the 25 subjects in Group 1, 21 drove all six scenarios. Some 80% of subjects in Group I and both subjects of Group II have the same educational level (Postgraduate); however, the income level is relatively higher among the subjects of Group I. The majority of the subjects (68%) in Group I are males while the gender is equally distributed in Group II. In addition, on average subjects in Group I are slightly older and their car ownership is higher than subjects in Group II. Fig. 2 presents the recruitment process and Table 2 presents the subjects' characteristics. Sixty-seven percent of participants were male and 33% female. The majority of subjects were between 26 and 45 years old. The income level was distributed fairly among different categories. The majority of the subjects owned one or two vehicles in their household. The authors tried to have an unbiased sample; however, it was challenging to find more women volunteers, and older drivers. Most of the subjects were students, faculty, and staff at Morgan State University.

The subjects drove scenarios after practicing with the driving simulator and becoming comfortable with its environment. The D-1 to D-3 and I-1 to I-3 scenarios were randomly given to the subjects anonymously; thus, some subjects drove on Ds and then Is, while others drove Is and then Ds. Most of the subjects were very familiar with the area and only 8% were completely unfamiliar (Fig. 3). The subjects had a strong willingness to change their route when observing the "ACCIDENT AHEAD TAKE THE DETOUR" sign as presented in Fig. 3. Subjects' willingness to change their route (divert) was asked on a five-point

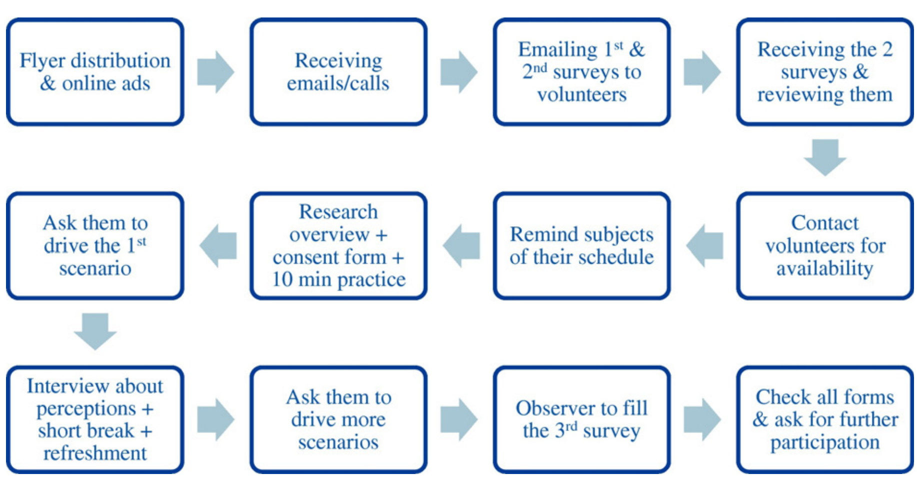

Fig. 2. Human subject recruitment and experiment process.

Table 2
Descriptive statistics of socioeconomic data.

Characteristics	Options	Percentages
Gender	Female	33
	Male	67
Income level	<$20K	20
	$20K–$30K	24
	$30K–$50K	4
	$50K–$75K	16
	$75K–$100K	16
	>$100K	20
Age	18–25	18
	26–35	33
	36–45	30
	46–55	4
	>55	15
Car ownership	0	4
	1	52
	2	33
	≥ 3	11

scale from 1 (the lowest willingness) to 5 (the most willingness) in the survey questionnaire.

Integrated scenarios (I) and DS-only scenarios (D) were compared to find the effect of integration in drivers' route choice decision. Over 92% of subjects were able to read both VMS contents (quantitative and qualitative) while driving in both I and D scenarios. However, the subjects believed that VMSs were more reliable in I scenarios than in Ds (Fig. 3). They were asked to rate VMS reliability from 1 (the least reliable) to 5 (the most reliable). Fig. 3 presents the average reliability score in D versus I scenarios.

In scenarios without travel time information, 81% of the subjects in I scenarios and 88% of those in D scenarios chose the major route (MD-395) which was the fastest path. These rates were changed to 80% (for Is) and 67% (for Ds) in the second pair of scenarios in the presence of travel time information with the same traffic volume as the first scenario pair. In the third scenario pair where the major route was not the fastest path and travel time information was provided, 71% of drivers in the Is and 57% of drivers in the Ds chose the fastest path. The latter case is consistent with the subjects' opinion that the VMS is more reliable in the I scenarios than in the Ds. Overall, in two scenario pairs with travel time information, 76% of chosen routes in the I scenarios were the fastest path recommended by VMS while this rate was 62% for the D scenarios. However, the subjects had a slightly higher route diversion rate in the D scenarios than the Is (Fig. 4).

Fig. 5 presents the diversion rate by route familiarity. Subjects who are completely familiar with the area diverted the most because they knew the alternative routes and were comfortable with switching their routes. Densities were higher in I scenarios than in D scenarios, from 3% to 160% in different road segments.

3.2. Why is integration better?

Comparing the results of the six scenarios revealed interesting results on Integration advantages compared to Non-Integrated scenarios. The two elements to support this idea are compliance rate and consistency level. For each scenario, the behavior is compliant (Comp) if the subject chooses the provided shortest path; otherwise it would be non-compliant (Non-Comp). Based on how the scenarios have been designed, the compliance rate could be investigated corresponding to scenario 3 (D-3/I-3). The default path is known as the experiential path [31]. If the subject choice in scenario 1 (D-1/I-1), in which the quantitative VMS is off, is similar to their Stated Preference (SP), which has been recorded on the second survey questionnaire, then it will be assumed that the subject had consistent route choice [32].

Information on the VMS in I-3 and D-3 scenarios is indicating that travel time (TT) on I-395 is 12 min, while the one for the Russell Street is 8 min. This represents the ΔTT (difference between I-395 and Russell St. travel time) equal to +4 min. In this condition, drivers were encouraged to choose Russell St. instead of I-395 or Washington Blvd. The overall compliance rate for integrated scenario 3 (I-3) is 70.8% while for the D-3 scenario it's 56.5%. The 14% higher compliance rate in the I-3 scenario appears to better match the reality assuming information provided by the VMS was used to optimize travel time. Fig. 6 demonstrates the probability of choosing I-395 on each I/D scenarios corresponding to ΔTT.

In the first scenario in which the quantitative VMS does not display anything (it is off), the drivers should choose their route based on

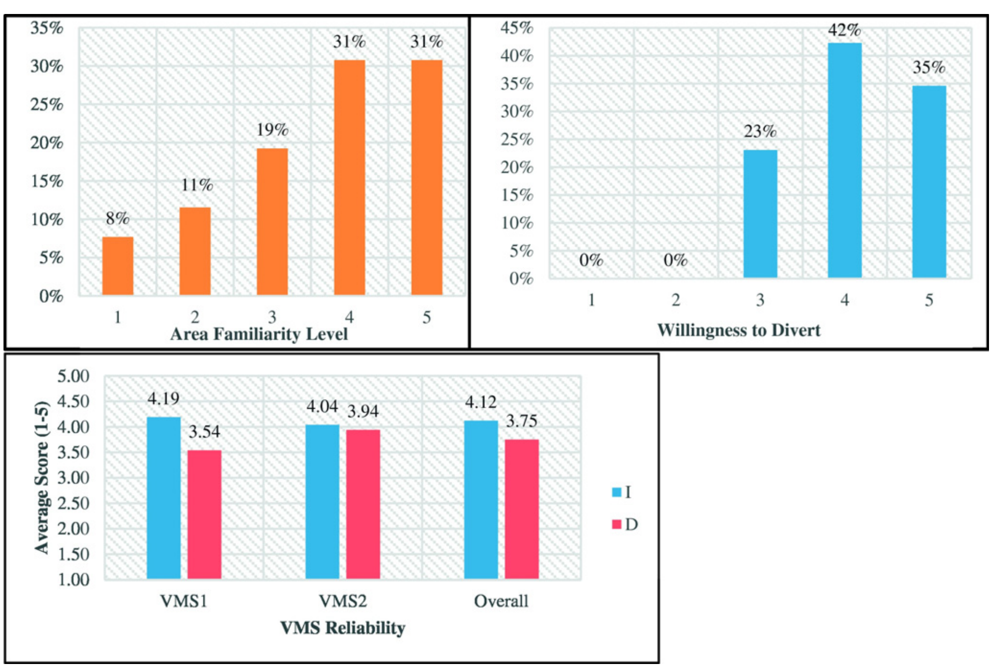

Fig. 3. Participants' familiarity to the area (top left figure), willingness to change route when observing “ACCIDENT AHEAD TAKE THE DETOUR” on VMS2 (top right figure), and VMS reliability (bottom figure).

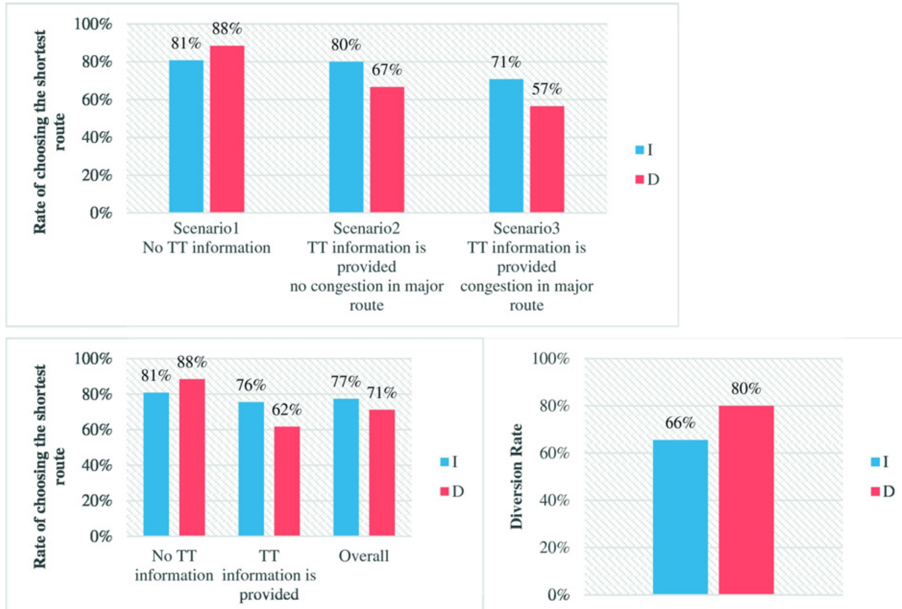

Fig. 4. Subjects' route choice behavior in each scenario (top figure), Subjects' route choice behavior based on provision of TT information (bottom left figure), Overall route diversion rate (bottom right figure).

their SP. Based on Google Map information on TT, ΔTT is −1 min; logically, drivers should chose I-395 as a shortest path. However, in the I scenario, they chose I-395 80% of the time, compared to 90% in the D scenario. In the second scenario in which the TT for both routes was the same, drivers chose I-395 almost 15% more in the I scenario. Interestingly, on I-3 while the TT on I-395 was 4 min more than Russell St., participants indicated more compliance behavior.

The first scenario of this study (I-1/D-1) is represented as a default condition without any information displayed on the quantitative VMS for different routes' TT. Among all participants, 45% cited I-395 as the preferred route while only 11% mentioned Russell St. as their preference in the questionnaire. Although consistency levels in both D-1 and I-1 scenarios regarding route choice of Russell St. are similar (50%), in the D-1 scenario, out of those individuals who chose the I-395 route, approximately 52% claimed their SP to be I-395. Exploring the consistency level in the I-1 scenario indicates a 6% increase compared to the D-1scenario. Thus individual's reactions are most likely to be consistent in the integrated approach. The overall results showed that people were quite responsive to VMS travel time information. Furthermore, the compliance rate with VMS information was found to be systematically higher in the I-3 scenario than in the D-3 scenario. Also, the drivers indicated higher consistency levels in the integrated environment.

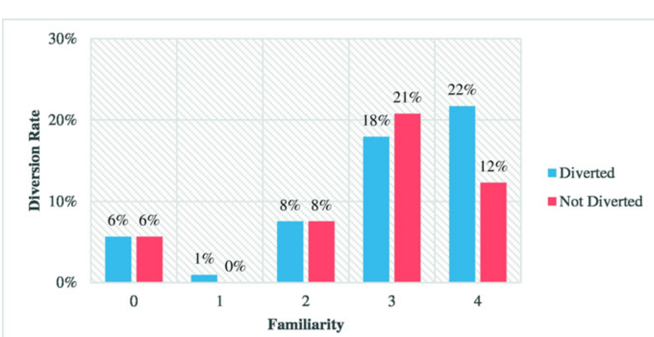

Fig. 5. Diversion rate in each familiarity level category.

4. Statistical analysis

This study investigated factors affecting diversion decisions and route choice behavior (dependent variables). To do so, first a bi-variate correlation analysis between the dependent variables (DV) and the 22 independent variables (IV) was conducted (Table 3). Then, multinomial logistic regression was utilized to define diversion decision and route choice behavior respectively.

Some variables are from the survey questionnaire, others from the driving simulator. Some variables (i.e., VMS helpfulness) are the subjects' general attitude before driving the simulator while others (i.e., VMS1&2 readability, VMS1&2 reliability) are based on their experience with the simulator. As presented in Table 3,VMS2 readability, route choice, scenarios, VMS2 and VMS1 reliability, drivers' attitude about VMS helpfulness, and drivers' exposure to VMS in real-world experience were correlated with diversion. In addition to five common IVs, the subjects' need to use GPS also has a significant correlation with route choice behavior. Note that VMS1 was located near the origin (before the route decision point) and showed travel times for each alternative route from the origin to the destination. VMS2 was located on each of the three alternative routes and suggested the drivers take the detour due to an accident.

Table 4 reports the regression results for the diversion model. Among candidate variables chosen from the correlation analysis, only the route chosen, VMS helpfulness, scenario, VMS exposure, VMS2

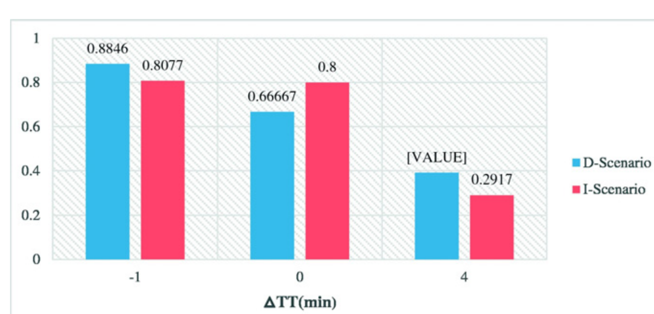

Fig. 6. Probability of choosing I-395 on D and I scenarios.

Table 3
Correlation coefficient between IVs and DVs (diversion and route choice).

IV	DV: diversion		DV: route choice		IV	DV: diversion		DV: route choice	
	Value	Sig.	Value	Sig.		Value	Sig.	Value	Sig.
Gender	0.015	0.853	−0.039	0.638	VMS1 reliability	0.039	0.727	−0.106	0.336
Age	−0.420	0.610	0.042	0.614	VMS2 reliability	0.276[a]	0.008	0.259[a]	0.014
Education level	−0.109	0.189	−0.073	0.375	Car Ownership	0.012	0.886	0.075	0.366
Income level	0.035	0.683	0.151	0.079	PTT	0.165[b]	0.045	−0.065	0.432
Driving mileage	0.120	0.146	0.042	0.614	ATT	0.178[b]	0.030	−0.201[b]	0.014
VMS exposure	0.175[b]	0.033	0.193[b]	0.018	PTT−ATT	0.052	0.527	0.086	0.301
VMS readability	0.121	0.143	0.116	0.161	Scenario	−0.366[a]	0.000	−0.348[a]	0.000
VMS attention	−0.002	0.983	0.023	0.777	VMS1 readability	0.249[a]	0.002	−0.313[a]	0.002
VMS helpfulness	0.236[a]	0.004	0.070	0.395	GPS	0.047	0.567	0.174[b]	0.034
Network familiarity	0.028	0.744	0.011	0.894	Route choice	0.396[a]	0.000	1	–
					Diversion	1	–	0.396[a]	0.000
Diversion willingness	−0.036	0.670	−0.134	0.111	VMS2 readability	−0.427[a]	0.000	−0.012	0.905

[a] Correlation is significant at the 0.01 level (two-tailed).
[b] Correlation is significant at the 0.05 level (two-tailed).

readability, PTT, and education level affect drivers' diversion decision. However, the coefficients of only the first three variables were significantly different from zero. If drivers took Exit 51 (Washington Blvd.) to get to the destination, the probability of diversion to other routes was higher than when they choose Exit 53 (MD-395) while this probability is lower for drivers who take Exit 52 (Russell St.). Scenarios 1 (D-1, I-1) and 2 (D-2, I-2) had a higher probability of diversion compared to Scenario 3 (I-3), in which VMS2 was off and drivers were not asked to divert. However, in Scenario 3, traffic congestion was similar to the other two scenarios. Diversion probability in Scenario D-3 was not significantly different from the one in Scenario I-3 (the base Scenario). This suggests that VMS presence increased diversion rate. It means that in the absence of VMS, if drivers observe traffic congestion, the probability of staying on their current route and not switching to another route is higher. However, the probability of route diversion increases if VMS informs them of an accident ahead and suggests following the detour. Subjects who believed VMS information was helpful tended to divert more than those who did not believe so. The model's overall goodness-of-fit presented in Table 4 is satisfactory.

Table 5 indicates the results of the multinomial regression explaining the route choice behavior of the subjects. In addition to scenarios and VMS exposure, actual travel time (ATT) and the need for GPS was found to be significantly correlated.

The diversion rate in this study is dramatically higher than in a similar study on route diversion in the absence of route guidance (i.e., GPS). A route diversion analysis done by Jeihani and Ardeshiri [33] was conducted through two series of SP surveys and DS experiments. According to the SP results, the diversion rate was 68% for work trips and 65% for leisure trips, compared to only 1% in the DS. Jindahra and Choocharukul [7], in a similar empirical SP data analysis in Thailand, asserted that the diversion rate was nearly 80% when the VMS displayed the cause of delay and suggested route information.

Many reasons may explain this inconsistency between the SP and DS. Xu et al. [34] asserted that factors such as time period and traffic conditions at off-ramps and downstream of the road distinguished field studies from the SP approach in typical driver behavior analysis. Chatterjee et al. [35] reached similar conclusions when the actual diversion rate was 80% less than what was stated in the questionnaire. Therefore, the presence of queue and traffic congestion significantly affects the diversion likelihood.

In the study conducted by Jeihani and Ardeshiri [36], the traffic generation in the DS could not exceed a particular volume of traffic. Due to this restriction, which produced fairly fluid downstream traffic, subjects might not perceive the necessity to divert. Qualitative information from the VMS, lack of information about a detour, and the unavailability of GPS might be other reasons for the low compliance rate. Some of these issues were addressed in this study and, therefore, the diversion rate went up to 80%.

Xu, Sun, Peng [34] concluded that travel time information on a VMS attracted more attention than traffic congestion information. Chatterjee et al. [35], in a similar study, surveyed the reaction of drivers to an active VMS and declared that while many drivers found VMS information useful in a pre-SP survey, only one-third actually saw the VMS information and a small portion of them followed the recommendation. Furthermore, Zhong et al. [31] suggested that besides drivers' characteristics, perception of information, VMS content, road familiarity, and even drivers' mood when they observed the VMS determined compliance behavior with VMS guidance.

5. Conclusion

Integrating a DS with a TS provides new tools to facilitate a better understanding of the human factors involved in the response to route

Table 4
Logistic regression model results (DV: diversion).

Variable	β	Standard error	Significance	Exp (β)
Route				
Route1	0.416	1.811	0.818	1.515
Route2	−2.058	0.583	0.0001	0.128
Scenario			0.000	
Scenario D-1	3.602	1.011	0.0001	36.689
Scenario I-1	2.601	0.950	0.006	13.473
Scenario D-2	4.706	1.100	0.0001	110.594
Scenario I-2	3.429	0.993	0.001	30.837
Scenario D-3	0.808	0.997	0.418	2.242
VMS helpfulness	1.131	0.336	0.001	3.099
Constant	−4.987	1.392	0.0001	
Cox & Snell $R^2 = 0.454$ Nagelkerke $R^2 = 0.611$				

Table 5
Multinomial logistic regression model results (DV: route choice).

Variable	β	Standard error	Significance	Exp (β)
ATT	0.272	0.099	0.006	1.312
Scenario			0.000	
Scenario D-1	−4.357	1.019	0.000	0.013
Scenario I-1	−3.591	0.847	0.000	0.028
Scenario D-2	−2.603	0.789	0.001	0.074
Scenario I-2	−3.084	0.784	0.000	0.046
Scenario D-3	−0.826	0.687	0.230	0.438
VMS exposure			0.009	
Never	4.505	1.511	0.003	90.501
Sometimes	1.732	0.817	0.034	5.650
Often	2.005	0.840	0.017	7.429
GPS			0.013	
Yes	1.352	0.57	0.018	3.866
Intercept	−2.907	1.099	0.008	
Cox & Snell $R^2 = 0.402$ Nagelkerke $R^2 = 0.519$				

guidance and ITS by taking advantage of a realistic traffic flow and density and a fairly realistic driving environment.

In this study, a DS (UC-win/Road) was integrated with a TS (S-Paramics). A 10 mi^2 (25 km^2) segment of a real-world network southwest of downtown Baltimore with ramps and intersections was developed and integrated. The integration was very challenging and time consuming. It needed trial and error to match the networks in the TS and the DS since no automatic integration is available at this point. The different nature, format, logic, and purpose of the TS and DS make it very difficult to integrate the two simulators. To the best knowledge of the authors, this study is the first attempt to integrate a DS and TS at the network level. The intersection and ramp inconsistencies between the two simulators could be a reason for the lack of network-level integration in the literature. The best solution might be improving traffic patterns by DS vendors or two vendors of TS and DS making an integrated software package. Vladisavljevic et al. [27] reached a similar conclusion and stated that the optimal solution for integration of the two simulation software would be a permanent platform for two-way communication between the software, provided by their developers, that requires compatibility of the software with each other. Otherwise the integration efforts may all be case-specific.

Integration is useful for long corridors and small road networks with few intersections, leading to more efficient lane utilization. The integrated network had a more realistic traffic pattern, higher traffic density, and higher VMS reliability than the DS-only one.

The results could be more realistic if complete real-time integration was possible and both software could work at the same time. Furthermore, if the graphical capabilities of TSs improve, a more realistic traffic behavior would be observed by the subjects. Adoption of the standard format, Road XML, by TSs and DSs would make the integration less challenging.

The case study of the effect of VMS on drivers' route choice and route diversion behavior indicated that drivers' attitudes and beliefs about VMS affected their compliance. A higher level of exposure to VMS resulted in a higher diversion rate and better route choice behavior. Subjects' socio-economic characteristics did not seem to affect either route diversion decisions or route choice behavior. The presence of VMS will increase route diversion rate. Furthermore, the presence of route guidance and detour information greatly affected route diversion rate.

The case study could be improved to include more participants to increase the diversity and reduce biasedness. Furthermore, encouraging each participant to drive more scenarios to find the effect of learning on route choice and diversion would be beneficial.

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