COMPARATIVE ANALYSIS OF YOUNG DRIVERS BEHAVIOR IN NORMAL AND SIMULATION CONDITIONS AT A RURAL ROAD

G. Yannis
NTUA
geyannis@central.ntua.gr

P. Papantoniou
NTUA
ppapant@central.ntua.gr

M. Nikas
NTUA
sonloredan@hotmail.com

ABSTRACT

The objective of this research is to compare the driving performance of young drivers in normal and simulation driving conditions. For this purpose, 31 young drivers aged 20-30 participated in an experimental process including driving both in a driving simulator as well in real traffic condition at an interurban road. A central component of the experimental design was the driving simulator scenario which was programmed in order to simulate with high precision the interurban road task. Proceeding to the statistical analysis, lognormal regression models were developed for the identification of the impact of driving environment (simulated and real road conditions), driver characteristics (mileage, age, gender), as well as driving performance variables (average acceleration, deceleration and standard deviations of them) to average vehicle speed change. Model results reveal that absolute values of drivers' traffic performance vary between simulated and real driving conditions. On the contrary, relative differences of driver behaviour at the two driving environments remain mostly the same. More precisely, speed difference between fast and slow drivers is the same at both driving environments, as the speed difference is also the same at the two driving environments between drivers conversing or not conversing to the passenger. Research results allow a clear view of the extent and manner in which driving conditions in conjunction with driver’s characteristics affect driving performance. Thus, they provide with a substantiated explanation for the reliability of the particular simulator measurements.

Keywords: driving simulator, road experiment, speed, lognormal regression, driving behavior, distraction

INTRODUCTION

Driving simulators allow for the examination of a range of driving performance measures in a controlled, relatively realistic and safe driving environment. Driving simulators, however, vary substantially in their characteristics, and this can affect their realism and the validity of the results obtained (Regan et.al, 2008).

Driving simulator validity constitutes one of the most critical issues of the adequacy of driving simulator use and it typically refers to the degree to which behaviour in a simulator corresponds to behaviour in real-world environments under the same conditions (Kaptein et.al, 1996; Blaauw, 1982). Similar research results indicate that the best method for determining the validity of a simulator is to compare driving performance in the simulator to driving performance in real vehicles under the same driving tasks (Blaauw, 1982).

There are two types of validity: absolute validity and relative validity. If the numerical values for certain tasks obtained from the simulator and actual vehicles are identical or near identical, absolute validity is said to have been achieved (Godley et.al, 2002). Relative validity is achieved when driving tasks have a similar affect (e.g., similar magnitude and direction of change) on driving performance in both the simulator and real vehicles (Harms, 1992). Although limited, research has generally found that simulators demonstrate good relative behavioral validity for many driving performance measures, although absolute validity has rarely been demonstrated (Godley et.al, 2002; Harms, 1996; Reed and Green, 1999; Lee, 2003)

Within this context, the objective of this research is to compare the driving performance of young drivers in normal and simulated driving conditions. For this purpose, 31 drivers aged 20-30 years old were asked to participate in an experimental process including driving both in a driving simulator as well in real traffic condition at an interurban road. The paper is structured as follows: In the beginning, the background of the research is provided including several similar researches on driving simulator validity. Then, in the methodology section the experimental procedure is presented regarding both the data collection as well as a first explanatory analysis of the results. Finally, the statistical models implemented regarding average speed is presented and discussed and some concluding remarks are provided.

BACKGROUND

Significant research has been conducted so far on driving simulator validity and there are various attempts to correlate the simulator results with those being extracted from trials in real traffic conditions. Relevant research started since the mid 1960's with Barrett et al. (1965) and is continuing until recent, with Godley et al. (2002), Kim et al. (2005), Miyajima et al. (2006), Hirata et al. (2007, Riener (2010).

Yan et.al. (2008) implemented a driving simulator experiment with eight scenarios at the intersection to determine if the subjects' speed behavior and traffic risk patterns in the driving simulator were similar to what were found at the real intersection. The experiment results showed that speed data observed from the field and in the simulator experiment both follow normal distributions and have equal means for each intersection approach, which validated the driving simulator in absolute terms. Furthermore, this study used an innovative approach of using surrogate safety measures from the simulator to contrast with the crash analysis for the field data.

Furthermore, Hirata et.al. (2007) presented an effort efforts to develop a driving simulation system, MOVIC-T4, for traffic safety analysis of underground urban expressways. In order to develop a small portable simulator, a small-sized motion-base with two-degrees-of-freedom is used to duplicate acceleration cueing together with a head-mounted-display (HMD) for the visual system.

An overview of this system is given and the reliability of driving data obtained from the experiments using MOVIC-T4 is discussed through a validation study using field driving data. The results of validation indicate that the perceived speed, distance headway, and physiological data in the simulator show the almost same trend as that in the real world, but larger decelerations tend to be produced in the simulator.

Blana and Golias (2002) investigated differences in lateral displacement when driving on curved and straight road sections in real-road and simulator conditions. This research estimated 100 licensed drivers on a rural road and 100 in a fixed-base simulator. Speed and lateral position on the real road were measured using videocameras. The analysis indicated that the mean vehicle lateral displacement is in general higher on the real road than in the simulator. However, these differences decrease for higher speeds at curved sections and for lower speeds at straight sections. It was also found that the standard deviation of the vehicle lateral displacement is significantly lower on the real road than the corresponding values in the simulator, at either curved or straight sections.

To evaluate a driving simulator, Underwood et.al. (2011) compared hazard detection while driving on roads, while watching short film clips recorded from a vehicle moving through traffic, and while driving through a simulated city in a fully instrumented fixed-base simulator with a 90 degree forward view (plus mirrors) that is under the speed/direction control of the driver. In all three situations results indicated increased scanning by more experienced and especially professional drivers, and earlier eye fixations on hazardous objects for experienced drivers.

Risko and Martens (2014), compared driver headway choice in a driving simulator and in an instrumented vehicle. Twenty-two participants carried out instructions to either change their headway to a specific value or to choose a headway as they would normally do. The speed of the lead vehicle (80, 100 or 120 km/h) as well as the target headway (1, 1.5, 2 s) were varied between trials. Specific headway instructions were provided in seconds as well as metres. The attained headways were compared between the virtual and the real environment. Results show no significant difference between headway choice in the simulator and on a real road, neither for self-chosen nor for instructed headways.

In another research, Jia et al. (2011), moved one step further, and suggested an approach for their simulator calibration through a correlation model, relying on measurements from trials in real traffic conditions. In order to develop this model, they used the distributions of the measured parameters.

METHODOLOGY

Data Collection

Within this research, an experimental process was designed including both driving in the driving simulator as well on-road in an instrumented vehicle in real traffic conditions.

The driving simulator experiment took taking place on Department of Transportation Planning and Engineering of the National Technical University of Athens (NTUA), where the FOERST Driving Simulator FPF is located. Foerst Driving Simulator is a quarter-cab simulator with a motion base and three 40" LCD monitors was used for the experiment. Furthermore, the on-road experiment took place on the suburbs of Athens, namely in the region of Paiania.

Figure 1: Driving simulator and on road experiment

Sample
The experiment concerned the driving performance of 31 young drivers aged between 20 and 30 years. The sample of drivers is consisted of 18 males and 13 females, most of which were students of the National Technical University of Athens with a valid driving license and an average driving experience of 4.5 years.

Questionnaires
After completed the driving simulator tasks, participants were asked to fill in a questionnaire. This questionnaire concerned their personal characteristics, distracted driving performance, driving habits and driving behaviour in case of a road accident.

Familiarization
A familiarization session is typically the first step of all experiments. The driving simulator provides a "Free Driving" scenario that familiarizes the participants with the demands of the simulator environment. Furthermore, another familiarization driving task was implemented in real driving conditions

During the familiarization with the simulator and the real car, the participant practiced in:

- handling the simulator and the experimental vehicle (starting, gears, wheel handling etc)
- keeping the lateral position of the vehicle
- keeping stable speed, appropriate for the road environment
- braking and immobilization of the vehicle

The familiarization process lasted approximately 10 minutes in each environment.

Randomisation
The first principle of an experimental design is randomization, which is a random process of assigning treatments to the experimental. The purpose of randomization is to remove bias and other sources of extraneous variation, which are not controllable. In this framework, the first half of participants had to first drive the route of simulator and then the pre-defined route on the road location - which was almost similar to the simulator's one – whereas the rest of participants executed the trials vice versa.

Experiment procedure
In the framework of the experiment two driving scenarios have been developed in order to compare the driving performance of young drivers in simulated and on-road driving conditions.

- In the driving simulator experiment, a rural route 2,1 km long, single carriageway and the lane width is 3m, with zero gradient and mild horizontal curves

- In the on-road experiment, a specific driving route was selected in order to have similar characteristics with the driving simulator scenario. More specifically, the selected route was consisted of an interurban route 1,9km long, single carriageway and lane of 3,5m width.

Figures 2 and 3 present the horizontal design of both driving scenarios. It is worth mentioning that a programming code has been developed - using the programming tool the simulator provides - in order to create the specific driving simulator route from the various 'maps' available in the simulator software. Initially, half of the participants were asked to drive first the route of simulator and then the pre-defined route on the road whereas the rest of participants executed the trials vice versa. In addition, each driver performed twice every route, without any distraction source and one conversing with the passenger.

After a tiny brake needed to return to the starting point and to restart the recorder, the driver drove the same route as in the first place but under the opposite talking scenario. Half of the participants drove firstly without conversation and half with conversation so that their familiarization with the simulator or the vehicle during the second drive would not influence the results. Each journey lasted approximately three minutes. Drivers were asked to follow their usual driving behaviour throughout the experiment and try not to be affected by any other factors.

Figure 1: Driving simulator route

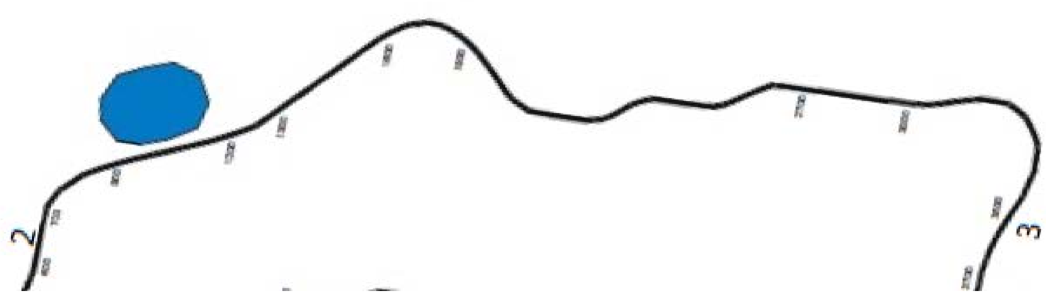

Figure 2: On-road route

The experiment was supervised by two researchers. The first researcher-coordinator of the experimental process guided the participants both to the driving simulator as well as to the on-road experiment. This researcher was sitting as a co-pilot near the driver and was responsible for the oral briefing of the participants, assisting the participants during their familiarization drive, filling in a checklist for the control of the experiment with any comments about anything remarkable about the driving of the participant, implementing the conversation task. The second researcher was responsible for the statistical editing of data output, the collection of the respective questionnaires and to assist for other secondary issues during the experiment.

Explanatory Analysis

Within the first part of the analysis absolute and relative values of driving performance measures were compared in order to give an overall impact of driving performance between simulated and real driving conditions.

Beginning with absolutely values, as expected, results revealed that vary between simulated and real driving conditions. Furthermore, the relative values of six driving performance parameters regarding the two driving conditions are provided in table 1.

Table 1: Comparative table of relative values between on-road and simulator experiments

Comparative table of relative values		Road		Simulator		**Road**	**Simulator**	$\bar{\Delta\chi}_{(Road)}$ - $\bar{\Delta\chi}_{(Simulator)}$	**±u*S$_{Dx}$**	**Result-Difference**
	Features	A	B	A	B	$\bar{\Delta\chi}_{(Road)}$	$\bar{\Delta\chi}_{(Simulator)}$			
Average Speed (V)	Talk	53,69	54,61	61,11	61,17	-0,92	-0,06	-0,86	3,554	**Non-Important**
	Age	54,51	53,72	62,35	59,67	0,79	2,68	-1,89	3,491	**Non-Important**
	Gender	55,93	51,69	64,18	56,94	4,23	7,24	-3,00	3,144	**Non-Important**
Average Acceleration (Acc)	Talk	2,53	2,65	1,07	1,10	-0,13	-0,03	-0,10	0,295	**Non-Important**
	Age	2,58	2,61	1,09	1,08	-0,03	0,01	-0,04	0,293	**Non-Important**
	Gender	2,70	2,43	1,11	1,05	0,27	0,06	0,21	0,291	**Non-Important**
Average Deceleration (Dec)	Talk	-2,21	-2,41	-1,27	-1,29	0,19	0,02	0,18	0,236	**Non-Important**
	Age	-2,28	-2,35	-1,32	-1,23	0,07	-0,09	0,16	0,236	**Non-Important**
	Gender	-2,40	-2,18	-1,31	-1,23	-0,22	-0,09	-0,13	0,238	**Non-Important**
Standard Deviation of Speed (StdevV)	Talk	16,02	17,11	16,33	16,25	-1,09	0,08	-1,17	1,583	**Non-Important**
	Age	16,24	16,95	16,83	15,63	-0,71	1,20	-1,90	1,532	**Important**
	Gender	17,37	15,45	17,02	15,28	1,93	1,74	0,19	1,522	**Non-Important**
Standard Deviation of Acceleration (StdevAcc)	Speech	3,68	4,01	0,55	0,55	-0,32	0,00	-0,32	0,602	**Non-Important**
	Age	3,65	4,09	0,54	0,56	-0,44	-0,01	-0,43	0,578	**Non-Important**
	Gender	4,11	3,48	0,57	0,52	0,62	0,06	0,57	0,605	**Non-Important**
Standard Deviation of Deceleration (StdevDec)	Talk	2,65	2,90	1,81	1,83	-0,25	-0,01	-0,24	0,475	**Non-Important**
	Age	2,64	2,94	1,88	1,75	-0,30	0,13	-0,43	0,461	**Non-Important**
	Gender	2,97	2,51	1,93	1,66	0,46	0,26	0,20	0,469	**Non-Important**

Categories: A - B= Talk – Non-Talk , <25 - >25 , Male – Female

Results from the comparative table of relative values lead to several initial conclusions. To begin with, the difference of the relative values of speed variability between the two driving environments in terms of the age groups is proved to be important. However, this result is not significant regarding the other who characteristics (gender and conversation with the passenger). On the other hand, for the remaining five driving performance measures, the difference of relative values in simulated and real conditions is not important

Analysis method

The impact of driving environment (simulated and real road conditions), basic driver characteristics (mileage, age, gender), as well as driving style (average acceleration, deceleration and standard deviations of them) on the average vehicle speed change was further analyzed through the development of statistical model by utilizing the SPSS statistical program. Specifically, as the logarithm of average speed was found to conform to a normal distribution, a log-normal linear regression model was developed.

$y_i = \Sigma\ \beta x_i + \varepsilon_i$

Where y_i is the response variable, x_i are continuous or discrete explanatory variables,

β are parameters to be estimated

and ε_i the error component $\varepsilon \sim N\ (0, \sigma 2)$

A variable was kept in the final model if the corresponding parameter estimate was significant at 90% confidence level, by means of t-tests a more relaxed confidence level was considered acceptable for the present analysis, given the relatively small sample size. In particular, a variable was considered statistically significant only if the respective value of the t-test was higher than 1.7 while the quality of the model was determined by means of the R^2 coefficient (Ben-Akiva and Lerman, 1985).

For the comparative assessment of variable effects within and across the model, relative effects (e*) were calculated, on the basis of elasticities (e). In particular, point estimates of elasticities (ei) are provided by the following formula, for each value (i) in the sample:

$ei = (\Delta Yi\ /\ \Delta Xi)\ .\ (Xi\ /\ Yi) = \beta i\ .\ (Xi\ /\ Yi)$

Estimating the responsiveness and sensitivity of the dependent variable with respect to changes in each independent variable was also needed to allow the comparison of the impact of different variables on using a mobile phone while driving. This was achieved by calculating the elasticity of each independent variable (Washington et.al, 2003). The elasticity value of a continuous variable is defined as the percentage change in the dependent variable resulting from small, incremental changes in an independent variable. Elasticity can be particularly useful because it is dimensionless, unlike any estimated coefficient of regression parameter, which depends on the units of measurement of each parameter. The relevant elasticity (e_i^*) of each variable was also calculated by dividing the elasticity of the specific variable by the elasticity of the variable with the lowest impact on the dependent variable. This allows for the classification of variables with respect to the magnitude of their effect on the dependent variable in a straightforward way.

Model Development

The variables were extracted not only from the simulator’s and smartphone’s data recordings of the two routes but from the survey questionnaire as well. A large number of variables were available, as shown in Table 2, where the variables available from the outputs of simulated and real condition trials range from 1 to 16, and the variables obtained from the questionnaire range from 17 to 23. Nevertheless, several other variables were not considered in the analysis.

Table 2: Variables Available for the Analysis

1	Average speed (km/h)
2	Logarithm of the average speed
3	Driving on real road conditions (0:no, 1:yes (simulator))
4	(0:no, 1:yes)
5	Distance covered at each trial (km)
6	V(NO TALK) – V(TALK) speed difference between talking and not talking scenario of each driver per driving environment (km) διαφορά ταχύτητας χωρίς ομιλία με την ταχύτητα με ομιλία κάθε οδηγού για κάθε περιβαλλον
7	Ratio of speed when not talking to speed when talking (km)
8	General acceleration -positive or negative-(m/s^2)
9	Acceleration (m/s^2)-positive
10	Logarithm of the acceleration
11	Deceleration (m/s^2)-negative
12	Logarithm of the deceleration
13	Standard deviation of speed
14	Standard deviation of General acceleration
15	Standard deviation of Acceleration
16	Standard deviation of Deceleration
17	Driving Environment
18	Age
19	Gender
20	Week days driving to work
21	Cautious driving while talking to passenger
22	Conversation is risky
23	Speed Reduction by 10-20Km/h

A log-normal linear regression model was developed for drivers' average speed and is shown in Table 3, in which the parameter estimates (β_i) and the related t values for each variable are presented together with the R^2 coefficient. Furthermore, the elasticity and relevant elasticity values for each independent variable used in the models are also recorder.

Table 3: Relative impact of independent variables on the model of mean speed

Independent Variables	**Average Driving Speed**			
	β_i	t	Relative Impact	
			e_i	e_i *
Driving Environment	0,069	9,797	0,0196	-3,76
Speed Difference with and without Conversation	-0,003	-2,389	-0,0052	1
Standard Deviation of Deceleration	0,019	5,194	0,0248	-4,75
Age	-0,021	-3,168	-0,0054	1,03
Gender	-0,040	-6,154	-0,0095	1,83

Week days driving to work	-0,004	-2,654	-0,0064	1,22
Cautious driving while talking to passenger	0,049	6,278	0,0063	-1,21
Conversation is risky	-0,024	-3,325	-0,0057	1,10
Speed Reduction by 10-20Km/h	-0,036	-4,737	-0,0059	1,14
R^2=0,659				

The R^2 value is fairly high and as a consequence the suitability of model can be considered as acceptable. Therefore, the examined independent variables can predict in a robust way the dependent one.

Results indicate that the only variables with a positive sign in the model are driving environment and variability of deceleration. Diving environment has the highest effect on average speed indicating that drivers in driving simulator drive in higher average speed compared with on road driving. Moreover, regarding the variability of deceleration drivers that achieved the highest standard deviation of deceleration drove in higher average speed in the respective driving scenario. On the other hand, several other parameters have a statistical significant effect on average speed model including driver characteristics (age, gender), variables extracted from the outputs of simulated and real condition trials (speed difference with and without conversation) as well as variables extracted from the respective questionnaire (week days driving to work, cautious driving while talking to passenger, conversation is risky, speed reduction by 10-20Km/h).

Moreover, based on the relevant elasticity values for each independent variable, the variable “speed difference with and without conversation” has the lowest on average speed. The sign of the bariable indicates that as long the speed difference is higher the average speed is lower. On the other hand, based again on the relative elasticity values, the variability of deceleration has the higher effect on average speed (4.8 times higher effect than speed difference with and without conversation.

CONCLUSIONS

The objective of this research is to compare the driving performance of young drivers in normal and simulation driving conditions. For this purpose, 31 drivers aged 20-30 years old were asked to participate in an experimental process including driving both in a driving simulator as well in real traffic condition at an interurban road.

Lognormal regression models were developed for the identification of the impact of driving environment (simulated and real road conditions), basic driver characteristics (mileage, age, gender), as well as the driving style (average acceleration, deceleration and standard deviations of them) to the average vehicle speed change.

Model results reveal that driving environment has the highest effect on average speed indicating that drivers in driving simulator drive in higher average speed compared with on road driving. Furthermore, absolute values of drivers' performance vary among simulated and real driving conditions. On the contrary, relative differences of driver behaviour at the two driving environments remain mostly the same. More precisely, speed difference between fast and slow drivers is the same at both driving environments, as the speed difference is also the same at the two driving environments between drivers conversing or not conversing to the passenger.

In this framework, average speed is significantly affected by the variability of deceleration as drivers that achieved the highest standard deviation of deceleration drove in higher average speed.

This is probably explained by the fact that while driving in low speed, low deceleration is achieved and as a consequence low variability in the average deceleration, while the opposite phaenomenon is occurred in higher average speed.
Research results allow a clear view of the extent and manner in which driving conditions in conjunction with driver's characteristics affect to driving performance. The next steps of the present research should focus on examining more driving parameters that significantly affect the driving behaviour among the different environments (simulated and real road conditions). Moreover, greater samples including drivers from all age groups, different traffic conditions (high/low traffic) as well as different road environments (urban road, motorway) should be examined in order to clearly estimate the total validity of the driving simulator.

REFERENCES

Barrett, G., Nelson, D., Kerber, H. (1965). Human factors evaluation of a driving simulator, Goodyear Aerospace Corporation, final Report

Ben-Akiva M., Lerman S. (1985). Discrete choice analysis, The MIT Press, Cambridge Massachusetts.

Blaauw, G. (1982). Driving experience and task demands in simulated and instrumented car: A validation study. Human Factors: The Journal of the Human Factors and Ergonomics Society, 473-486

Blana, E., Golias, G. (2002). Differences between Vehicle Lateral Displacement on the Road and in a Fixed-Base Simulator, Human Factors: The Journal of the Human Factors and Ergonomics Society, p. 44-303

Godley, S., Triggs, T. Fildes, B. (2002). "Driving simulator validation for speed research". Accident Analysis and Prevention, Vol. 34, pp. 589-600

Harms, L. (1996). Driving performance on a real road and in a driving simulator: Results of a validation study. In A..

Hirata, T., Yai, T., Takawaga, T. (2007). Development of the Driving Simulation System MOVIC-T4 and Its Validation Using Field Driving Data, Tsinghua Science and Technology, Volume 12, Number2, pp 141-150

Jia, L., Lu, M., & Wang, J. (2011). Using real-world data to calibrate a driving simulator measuring lateral driving behaviour. Intelligent Transport Systems, IET, Vol. 5, No.1, pp. 21-31.

Kaptein, N., Van der Horst, R., Hoekstra, A (1996). Visual information in a driving simulator: A study on braking behavior and time-to-collision. TNO Human Factors Research Institute, Soesterberg, the Netherland

Kim, J., Matsui, Y., Hayakawa, S., Suzuki, T., Okuma, S., and Tsuchida, N. (2005): Acquisition and Modeling of Driving Skills by Using Three Dimensional Driving Simulator. IEICE Transactions on Fundamentals of Electronics E88-A, 3, 770-778

Lee, H. 2003. The validity of driving simulator to measure on-road driving performance of older drivers. Transport Engineering in Australia, 89-100

Miyajima, C., Nishiwaki, Y., Ozawa, K., Wakita, T., Itou, K. and Takeda, K. (2006). "Cepstral analysis of driving behavioral signals for driver identification". In Proceedings of IEEE International Conference on Acoustics, Speech and Signal, Vol. 5, pp. 921-924.

Reed, M.P. and Green, P.A. (1999): Comparison of driving performance on-road and in a lowcost simulator using a concurrent telephone dialling task. Ergonomics 42, 8, 1015-1037

Regan M.L., Lee J.D., Young K., (2008). Driver distraction: theory, effects, and mitigation. CRC Press

Riener, A. (2010). "Assessment of Simulator Fidelity and Validity in Simulator and On-the-road Studies". International Journal on Advances in Systems and Measurements, Vol. 3, No. 3&4, pp. 110-124.

Risto, M. and Martens, M. (2014). Driver headway choice: A comparison between driving simulator and real-road driving, Transportation Research Part F: Traffic Psychology and Behaviour, Volume 25, Part A, Pages 1–9

Underwood, G., Crundall, D., Chapman, P. (2011). Driving simulator validation with hazard perception, Transportation Research Part F Traffic Psychology and Behaviour, 14(6):435–446

Washington, S., Karlaftis, M., Mannering, F. (2003). Statistical and Econometric Methods for Transportation Data Analysis. Chapman & Hall / CRC Press. Boca Raton FL.

Yan, X., Abdel-Aty, M., Radwan, E., Wang, X., & Chilakapati, P. (2008). Validating a driving simulator using surrogate safety measures. Accident Analysis and Prevention, 274-288