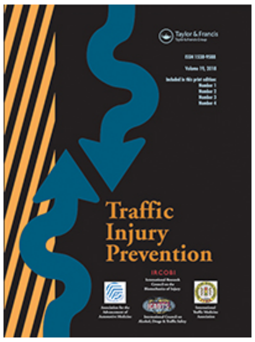

Traffic Injury Prevention

ISSN: 1538-9588 (Print) 1538-957X (Online) Journal homepage: https://www.tandfonline.com/loi/gcpi20

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To cite this article: Panagiotis Papantoniou (2018) Structural equation model analysis for the evaluation of overall driving performance: A driving simulator study focusing on driver distraction, Traffic Injury Prevention, 19:3, 317-325, DOI: 10.1080/15389588.2017.1398825

To link to this article: https://doi.org/10.1080/15389588.2017.1398825

Published online: 16 Feb 2018.

TRAFFIC INJURY PREVENTION
2018, VOL. 19, NO. 3, 317–325
https://doi.org/10.1080/15389588.2017.1398825

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Structural equation model analysis for the evaluation of overall driving performance: A driving simulator study focusing on driver distraction

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ABSTRACT

Objective: The present research relies on 2 main objectives. The first is to investigate whether latent model analysis through a structural equation model can be implemented on driving simulator data in order to define an unobserved driving performance variable. Subsequently, the second objective is to investigate and quantify the effect of several risk factors including distraction sources, driver characteristics, and road and traffic environment on the overall driving performance and not in independent driving performance measures.

Methods: For the scope of the present research, 95 participants from all age groups were asked to drive under different types of distraction (conversation with passenger, cell phone use) in urban and rural road environments with low and high traffic volume in a driving simulator experiment. Then, in the framework of the statistical analysis, a correlation table is presented investigating any of a broad class of statistical relationships between driving simulator measures and a structural equation model is developed in which overall driving performance is estimated as a latent variable based on several individual driving simulator measures.

Results: Results confirm the suitability of the structural equation model and indicate that the selection of the specific performance measures that define overall performance should be guided by a rule of representativeness between the selected variables. Moreover, results indicate that conversation with the passenger was not found to have a statistically significant effect, indicating that drivers do not change their performance while conversing with a passenger compared to undistracted driving. On the other hand, results support the hypothesis that cell phone use has a negative effect on driving performance. Furthermore, regarding driver characteristics, age, gender, and experience all have a significant effect on driving performance, indicating that driver-related characteristics play the most crucial role in overall driving performance.

Conclusions: The findings of this study allow a new approach to the investigation of driving behavior in driving simulator experiments and in general. By the successful implementation of the structural equation model, driving behavior can be assessed in terms of overall performance and not through individual performance measures, which allows an important scientific step forward from piecemeal analyses to a sound combined analysis of the interrelationship between several risk factors and overall driving performance.

ARTICLE HISTORY
Received 18 July 2017
Accepted 26 October 2017

KEYWORDS
Driving performance; structural equation models; driving simulator; road safety; driver distraction

Introduction

Driving is a complex task, requiring the interaction and coordination of various cognitive, physical, sensory, and psychomotor skills. It also requires a substantial degree of attention and concentration on the part of the driver (Beirness et al. 2002; Peters and Peters 2001). When driving, drivers must continually allocate their attentional resources to both driving and non-driving tasks. Because many aspects of the driving task become automated with experience, drivers are often capable of dividing their attention between concurrent tasks without any serious consequences to driving performance or safety (Young and Regan 2007).

Driver behavior research often makes use of driving simulators, because they 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. Despite these limitations, driving simulators are an increasingly popular tool for measuring and analyzing driving performance, driver distraction, etc., and numerous studies have been conducted, particularly in the last decade (Regan et al. 2008).

Considering that the present research aims to examine overall driving performance of participants, a very critical issue that should be taken into consideration is simulator validity, which typically refers to the degree to which behavior in a simulator corresponds to behavior in real-world environments under the same condition (Blaauw 1982; Kaptei et al. 1996). The best method for determining the validity of a simulator is to compare driving performance in the simulator to driving performance in real vehicles using the same driving tasks (Blaauw 1982). Several studies have examined driving simulator validity and have generally found good correlations between simulated driving performance and driving performance on real roads

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Associate Editor Alessandro Calvi oversaw the review of this article.

(Engström et al. 2005; Kaptei et al. 1996). There are 2 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 nearly identical, absolute validity is said to have been achieved (Godley et al. 2002; Harms 1992). Relative validity is achieved when driving tasks have a similar effect (e.g., similar magnitude and direction of change) on driving performance in both the simulator and real vehicles (Harms 1992).

Human factors research examines the way in which people interact with various aspects of the world and aims to make these interactions safer, healthier, and more efficient. In the context of safety features and road safety, human factors research aims to understand the driver's role in the safe operation of his or her vehicle (World Health Organization 2015). Human factors are not necessarily limited to unsafe driving behavior like excessive speeding and tailgating. Age, driving experience, attention level, and vehicle maintenance can all have an effect downstream on the performance of safety features. Drivers are an indispensable part of the road safety system, so factors that affect drivers accordingly affect road safety in general (Pavlou 2016).

Though human factors involve many specific factors that may be considered as accident causes, including driver injudicious action, driver error or reaction, behavior or inexperience, driver distraction, driver impairment (Department for Transport 2009), in the last 2 decades, there has been a focus on investigating the effect of distraction on driving performance. The term *distraction* has been defined as

> a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver's awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes. (Young and Regan 2007, p. 385)

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). In-vehicle sources of distraction include the use of cell phone (either for conversing or for texting), conversation with passengers, smoking, eating or drinking, listening to music, and in-vehicle assistance systems (e.g., navigation systems; Johnson et al. 2004; Neyens and Boyle 2008), and their effects are largely examined by means of simulator experiments (Bellinger et al. 2009; Horberry et al. 2006; Yannis et al. 2014). Numerous studies have sought to examine the relative effects of handheld and hands-free mobile phones on driving performance. Research findings have typically revealed that using a handheld phone degrades driving performance significantly and, in response, many countries have prohibited the use of handheld cell phones while driving (Matthews et al. 2003). Based on the results of numerous studies examining handheld cell phones, researchers concluded that the main risk associated with cell phone use while driving was the physical interference caused by handling and manipulating the phone (Briem and Hedman 1995; Brookhuis et al. 1991). However, as subsequent research discovered, although the physical distraction associated with handling the phone can present a significant safety hazard, the cognitive distraction associated with being engaged in a conversation can also have a considerable effect on driving. Indeed, many studies have found that conversing on a hands-free phone while driving is no safer than using a handheld phone (Haigney et al. 2000; Matthews et al. 2003; Redelmeier and Tibshirani 1997; Strayer et al. 2003).

A number of studies have examined the interaction between the performance of an in-vehicle nondriving task and the complexity of the driving environment (Cooper et al. 2009; Stavrinos et al. 2013; Strayer et al. 2003). Focusing on the effect of traffic conditions, using a driving simulator, Strayer et al. (2003) found that conversing on a hands-free mobile phone while driving led to an increase in reaction times to a lead braking vehicle, and this impairment in reaction times became more pronounced as the density of the traffic increased. Strayer and Johnston (2001) examined what additional effect increasing the complexity of the driving environment had on pursuit tracking performance while using a mobile phone. Results revealed that, when using the mobile phone, participants missed almost twice as many tracking targets as when they were not using a mobile phone and that this effect was most pronounced when performing the difficult tracking task under a demanding driving environment.

Within this framework, a very important remark relevant to the present research concerns the measures used to express driving performance in driver distraction studies and in general. The parameters for assessing driving performance vary significantly, and the driving-related outcomes have been analyzed in several studies as presented below: speed (Beede and Kass 2006; Yannis et al. 2010), lane position (Engström et al. 2005; Horrey and Wickens 2006; Liang and Lee 2010), accident probability (Papantoniou, Antoniou, et al. 2015), number of eye glances (Liang et al. 2007), headway (Ranney et al. 2005; Strayer and Drews 2004; Strayer et al. 2003), reaction time (Hancock et al. 2003; Horrey and Wickens 2006; Ishigami and Klein 2009). Certainly, a more holistic approach would be beneficial, whereby many independent variables used in concert will describe the overall performance capturing the effect of many variables together with their interrelationships

Based on the above, some key limitations can be identified and are addressed in the present research. The first concerns the methodological process. Driving performance is a multidimensional phenomenon, which means that no single driving performance parameter can capture all aspects of the overall driving performance. The large number of parameters that are estimated in each experimental process indicates that the decision regarding which parameter or set of parameters is used should be guided by the specific research question. However, in many studies where the research question is the investigation of driving performance, individual driving parameters are considered to represent performance. Instead, an unobserved (latent) new variable can be developed based on the collected individual parameters and represent with a statistical significance the overall driving performance.

The second limitation concerns the statistical analysis methodologies implemented in driving performance studies based on driving simulator experiments. More specifically, latent model analysis and, more specifically, structural equation models (SEMs) have rarely been implemented in the field of driving behavior. Structural equation models have been previously applied to many areas of transportation including transit system quality of service analysis (Karlaftis et al. 2001), travel behavior modeling (Golob 2003), mode choice modeling (Johansson et al. 2006), driver behavior modeling (Hassan and Abdel-Aty 2011), and public acceptability analysis of new technologies for traffic management (Chung et al. 2012). SEMs may be viewed as a generalized case of multivariate classical statistical models and suffer from similar constraints as classical statistical models but outperform other techniques due to their ability to treat auto-correlated errors, nonnormal data, and latent variables (Karlaftis et al. 2001).

Within the above open issues, the present research has 2 different aims. The first is to investigate whether this type of analysis can be implemented on driving simulator data. The second aim is to investigate and quantify the effect of several risk factors including distraction sources, driver characteristics, road, and traffic environment on the overall driving performance and not specific driving performance measures. Considering that this effect has not been tested thus far in the literature, the present work does not rely on any specific hypothesis but aims to act as a guide for the type of measures that can represent overall driving performance through SEMs in driving simulator experiments and in general. For this purpose, 95 participants from all age groups were asked to drive under different types of distraction in urban and rural road environments with low and high traffic volumes in a driving simulator experiment. Then, the development of an advanced statistical analysis methodology that consists of descriptive statistics as well as latent model analysis was carried out and are presented in the next sections. Finally, the results of the study are discussed and future work is outlined.

Methodology

In general, each experiment is based on a combination of conditions, resulting from the combinations of levels of the variables of interest. The complete combination of all levels of the variables of interest results in a full-factorial design. To achieve the above objectives and to collect the data for the analysis, a full-factorial driving simulator experiment was designed in which participants drove in 2 levels of environment (urban, rural) × 2 levels of traffic (Low (QL), High (QH)) × 3 levels of distraction, for a total of 12 experimental conditions.

Participants

Within the framework of the present study, 111 participants started the driving simulator experiment. Almost 18% (16 participants) were eliminated from the study because they had simulator sickness issues from the very beginning of the driving simulator experiment. As a result, 95 participants participated in the driving simulator experiment; almost half of the participants were males (47) and half were females (48). Furthermore, to investigate age characteristics, 3 age groups were created. Of the 95 participants, 28 were young drivers aged 18–34 years old, 31 were middle-aged drivers aged 35–54 years old, and 36 were older drivers aged 55–75 years old. In addition, the average number of years of education was 15.5 for the whole sample and the average number of years of driving 25.45, indicating that most participants were experienced drivers.

Overview of the experiment

In the present research, a driving simulator experiment took place including different driving scenarios. The design of the driving scenarios was a central component of the experiment and includes driving in different road and traffic conditions, such as in a rural, urban area with high and low traffic volumes and with different distraction sources.

More specifically, this assessment included an urban driving session with 6 trials and a rural driving session with 6 trials. These trials aimed to assess driving performance under typical conditions, with or without external distraction sources. The driving simulator experiment took place at the Department of Transportation Planning and Engineering of the National Technical University of Athens, where the Foerst Driving Simulator FPF is located.

The driving simulator consisted of 3 LCD wide-screen 40-in. (full high-definition), total angle view 170°, driving position, and support base. The dimensions at full development were 230 × 180 cm with a base width of 78 cm. It featured an adjustable driver seat, 27-cm-diameter steering wheel, pedals (throttle, brake, clutch), dashboard, and 2 external and one central mirror that appeared on the side and on the main screen and displayed objects and events that were happening behind the "vehicle" in real time. The controls available to the driver were 5 gears plus reverse gear, flash, wipers, lights, horn, brake, and starter (Figure 1).

The overall methodological procedure is presented in the next sections, including the research team, instructions to participants, practice drive, experimental drive, sequence of trials, incidents that took place, and questionnaires implemented.

Research team

The role of the coordinator (first researcher) was to welcome and guide the participants to the driving simulator at the specified date and time. The researcher was responsible for oral briefing and delivery of the instructions to the participant, assisting the participant during the familiarization drive, assisting the participant in completing the self-assessment and memory questionnaire, completing a checklist for the control of the experiment with any comments related to anything remarkable regarding the participant's driving, monitoring and

Figure 1. Driving simulator.

handling simulator sickness, conducting the driving simulator experiment, and assisting the participant with any other issues.

The role of the second researcher was to perform the distraction tasks during the experiment (the conversation task and the phone call with the participant), assist with any other secondary issues during the experiment, organize the files generated from the participants' driving, and edit the statistical data.

Instructions

The first step of the procedure was to inform the participant orally and in writing regarding the full procedure of the experiment (completion of the questionnaire, total duration, driving preparation, etc.). Maintenance of participants' usual driving behaviors was emphasized as well as avoiding being affected by other factors (stress, fear, etc.).

Figure 2. Top: Rural route, Bottom: Urban route.

Practice drive

A familiarization session or practice drive is typically the first step of all simulator experiments. The driving simulator provided a "free driving" scenario that familiarizes the participants with the demands of an everyday drive. The greater part of the drive was designed in an interurban environment, but there was also a short crossing through a small city with traffic signals and junctions. During the practice drive, the participant practiced handling the simulator (starting, gears, wheel handling, etc.), keeping the lateral position of the vehicle, maintaining constant speed appropriate for the road environment, as well as braking and stopping the vehicle. When the above-mentioned criteria were satisfied, the participant moved on to the next phase of the experiment. It should be highlighted that there was no exact time restriction for this procedure.

Experimental drive

After the practice drive, each participant drove 2 sessions (approximately 20 min each). Each session corresponded to a different road environment and consisted of 6 trials. It is worth mentioning that a programming code was developed, using the programming tool the simulator provides, to provide these specific routes from the various maps available in the simulator software.

- A rural route (first session) that was 2.1 km long, with mixed traffic, lane width 3 m, zero gradient, and mild horizontal curves (Figure 2, top).
- An urban route (second session) that was 1.7 km long, with mixed traffic, separated by guardrails, and lane width of 3.5 m. Moreover, narrow sidewalks, commercial uses, and parking are available at the roadsides. Two traffic-controlled junctions, one stop-controlled junction, and one roundabout were placed along the route (Figure 2, bottom).

Within each area type, 2 traffic and 3 distraction conditions were examined in a full-factorial within-subject design. The distraction conditions examined concerned undistracted driving, driving while conversing with a passenger, and driving while conversing on a cell phone.

Within the present research, a key parameter was the traffic volume experienced by the driver. Consequently, the behavior of specific vehicles or their response to driver behavior was not a priority for the experiment design and could be covered by the default traffic behavior features of ambient traffic in the simulator. Therefore, a probabilistic simulation of traffic conditions was chosen and 2 traffic scenarios were examined:

- QL: Moderate traffic conditions with ambient vehicles' arrivals drawn from a gamma distribution with mean of 12 s and variance of 6 s^2, corresponding to an average traffic volume of 300 vehicles/h in both directions.
- QH: High traffic conditions with ambient vehicles' arrivals drawn from a gamma distribution with mean of 6 s and variance of 3 s^2, corresponding to an average traffic volume of 600 vehicles/h in both directions.

These traffic arrival distributions were appropriate for describing vehicle arrivals for the given traffic flow, whereas gamma distributions are typical for describing vehicle arrivals for moderate to high traffic flows (Frantzeskakis and Giannopoulos 1986). The selected gamma distributions were chose for post-pilot testing of various alternative combinations of distribution parameters with respect to theoretical and practical issues, including the simulated result on the virtual screen.

Finally, as mentioned above, each driving trial was about a different driving distraction factor and different level of traffic volume. The trials that demanded conversation as a distractor (4 trials regarding the cell phone distraction and 4 trials regarding the passenger distraction) covered the following topics: family, origin, accommodation, traveling, geography, interests, hobbies, everyday life, news, business. It should also be mentioned that the conversation was continued during the whole period of each trial. One researcher was responsible for performing all distraction tasks during the experiment by sitting near the simulator to act as a passenger and by calling the participant in his mobile phone task.

Sequence of trials

To remove bias and other sources of extraneous variation that are not controllable, counterbalance in the driving trials was implemented in the sequence of the traffic scenarios and distraction scenarios in which the participant was going to drive but not in the order of area type (urban/rural). Rural scenario was always first for 2 reasons. Firstly, because a full counterbalance would demand a large number of participants in order to be implemented properly and, secondly, because the urban area led to more simulator sickness issues for the participants due to the more complex driving environment. It was concluded that full counterbalance is not meaningful, because a large number of combinations would be obtained; thus, a limited number of combinations for each variable was selected. These scenarios were assigned to participants in a counterbalanced way, so that eventually equal proportions of similar groups of participants were assigned to each scenario. The above scenarios were programmed by means of a programming software tool of the driving simulator, in a scripting language supported by the simulator environment.

Incidents

During each trial of the experiment, 2 unexpected incidents were scheduled to occur at fixed points along each drive (but not at the exact same point in all trials, to minimize learning effects). More specifically, incidents in the rural area concerned the sudden appearance of an animal (deer or donkey) on the roadway and incidents in urban areas concerned a car getting out of a parking position or the sudden appearance of an adult pedestrian or a child chasing a ball on the roadway. The objective of these incidents was to estimate the reaction time of the driver, a continuous variable defined as the time between the first appearance of the incident on the road and the moment the driver starts to brake (in milliseconds).

Questionnaire

Each participant was requested to fill in a questionnaire about their driving habits and behavior. The questions were chosen carefully based on the existing literature on drivers' self-reported behavior (Lajunen and Summala 1995; Vardaki and Karlaftis 2011). The questionnaire included demographic characteristics, driving experience, self-assessment, distraction-related driving habits, emotions and behaviors of the driver, anger expression inventory during driving, and history of accidents.

Analysis methods

Structural equation models are a type of latent model analysis. This type of analysis is used to deal with several difficult modeling challenges, including cases in which some variables of interest are unobservable or latent and are measured using one or more exogenous variables (Washington et al. 2011). In the present research, unobserved driving performance is investigated through this type of analysis.

Structural equation models have 2 components, a measurement model and a structural model. The measurement model is concerned with how well various measured exogenous variables measure latent variables. A classical factor analysis is a measurement model and determines how well various variables load on several factors or latent variables. The structural model is concerned with how the model variables are related to one another. Structural equation models allow for direct, indirect, and associative relationships to be explicitly modeled, unlike ordinary regression techniques with implicit model associations (Washington et al. 2011). Furthermore, a very useful tool regarding the interpretation of the results is path analysis, which was introduced by Wright (1934) as a method for studying the direct and indirect effects of variables. The quintessential feature of path analysis is a diagram showing how a set of explanatory variables can influence a dependent variable under consideration. How the paths are drawn determines whether the explanatory variables are correlated causes, mediated causes, or independent causes.

Finally, although model goodness-of-fit measures are an important part of any statistical model assessment, goodness-of-fit measures in structural equation models are an unsettled topic, primarily because of lack of consensus on which goodness-of-fit measures serve as "best" measures of model fit to empirical data (Arbuckle and Wothke 1995). Several research works have discussed these debates and a multitude of SEM goodness-of-fit methods, such as Mulaik et al. (1989), MacCallum (1990), and Steiger (1990). One of the most common goodness-of-fit measures is standardized root average square residual (SRMR), which is an index of the average of standardized residuals between the observed and the hypothesized covariance matrices (Chen 2007). Values of the SRMR range between zero and one, with well-fitting models having values less than 0.08.

Results

Considering the large data set from the driving simulator experiment, information regarding the data processing are presented below. Data storage was performed automatically at the end of each experiment. The data were stored in text format (*.txt). The simulator records data at intervals of 33 to 50 ms. The final master file, which was extracted in both .xls and .csv formats, included in total 95 rows × 863 columns ((95 participants) × (7 general information variables + 535 driving at the simulator variables + 321 questionnaire variables). All statistical analyses were implemented using the R statistical program.

Before proceeding to the main statistical analysis procedure, a correlation table is developed to investigate any of a broad class of statistical relationships between driving simulator variables. For this purpose, a Pearson's correlation coefficient table is created and presented in Table 1 regarding all continuous variables extracted from the driving simulator.

Pearson's correlation coefficient (r) is a measure of the strength of the association between the 2 variables. A positive correlation indicates that both variables increase or decrease together, whereas a negative correlation indicates that as one variable increases, the other decreases and vice versa.

Table 1 determines the relationships between 10 continuous driving performance variables that are recorder from the driving simulator, and a description of these variables is presented in Table 2. It should be noted that except for reaction time, which was measured at the point of each unexpected incident, all variables were measured as the average value of each driving session.

Results indicate that the highest correlation is between average speed and average gear (0.715) as expected. Furthermore, average speed is highly correlated with the lateral position of the vehicle. On the other hand, the reaction time of drivers for unexpected incidents has low correlation coefficients, indicating that there is not a strong correlation between these pairs of variables.

Table 1. Correlation table.

	Speed	Lateral position	Direction	Average brake	Average gear	Motor revolution	Space headway	Time headway	Time to line	Reaction time
Speed	1.000									
Lateral position	− 0.689	1.000								
Direction	0.290	− 0.093	1.000							
Average brake	− 0.140	0.429	0.234	1.000						
Average gear	0.715	− 0.574	0.092	− 0.279	1.000					
Motor revolution	0.561	− 0.385	0.268	− 0.010	− 0.079	1.000				
Space headway	0.272	− 0.569	− 0.106	− 0.497	0.277	0.168	1.000			
Time headway	− 0.258	− 0.002	− 0.161	− 0.176	− 0.175	− 0.107	0.499	1.000		
Time to line crossing	− 0.617	0.647	− 0.068	0.432	− 0.498	− 0.380	− 0.487	0.029	1.000	
Reaction time	− 0.034	− 0.145	− 0.077	0.220	− 0.041	0.098	0.281	0.203	− 0.194	1.000

The target is to estimate the effect of driver distraction a well as other factors on the overall driving performance. For this purpose, through the implementation of latent model analysis, in the first step, driving performance is defined as a new, unobserved variable, based on specific driving simulator parameters, and in the second step, the effects of distraction and driver, as well as road and traffic characteristics are estimated on this new driving performance variable (instead of being estimated on individual driving performance parameters). It should be noted that all driving simulator variables were evaluated (including the standard deviation of each variable) within this part of the analysis. The estimation results for both steps of the structural equation model are presented in Table 3.

Regarding the assessment of the statistical model, the value of SRMR is used. It is noted that values of the SRMR range between zero and one, with well-fitting models having values less than 0.08. Considering that the obtained value of SRMR in the present model is 0.061, the overall statistical model is accepted.

The respective path diagram is presented in Figure 3. Green lines express a positive correlation and red lines express a negative one. Furthermore, dashed lines indicate which variables create the latent one (first part of the SEM) and continuous lines indicate which variables exist in the regression part of the SEM. Finally, the label values represent the standardized parameter estimates.

Model results indicate that in the measurement model of the overall SEM, driving performance (the latent variable) is positively correlated with average speed and average gear and negatively corellated with time to line crossing and lateral position variability. In order to interpretate the results, definінions of the variables are presented:

Table 2. Driving simulator variables.

Name of variable	Description
Speed	Actual speed (km/h)
Lateral position	Track of the vehicle from the middle of the road (m)
Direction	Direction of the vehicle compared to the road direction (°)
Average brake	Brake pedal position (%)
Average gear	Chosen gear (0 (idle), …, 6 (reverse))
Motor revolution	Motor revolution (1/min)
Average space headway	Distance to the vehicle ahead (m)
Time headway	Time to the vehicle ahead (s)
Time to line crossing	Time until the road border line is exceeded (s)
Reaction time	Reaction time to the unexpected incident (s)

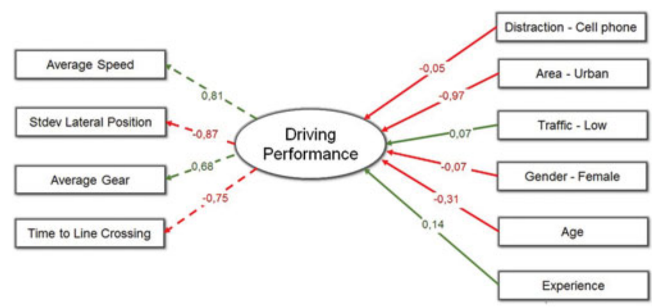

Figure 3. Path diagram of the Structural Equation Model.

- Average speed refers to the mean speed (km/h) of the driver along the route, excluding the small sections in which incidents occurred and excluding junction areas.
- SD lateral position refers to the variability (standard deviation) of the lateral position of the vehicle.
- Time to line crossing refers to the time until the road border line is exceeded (s).
- Average gear refers to the average chosen gear (0 = idle, 6 = reverse) of the simulator gear box along the driving route.

A first methodological finding is that from the 10 examined driving simulator parameters, only 4 participate in the development of the new unobserved driving performance behavior, including longitudinal (speed), lateral (standard deviation of the lateral position), average gear, and time until the road border line is exceeded.

In the structural model of the overall SEM, the new driving performance variable is the dependent variable and the statistically significant independent variables include cell phone use, area type, traffic conditions, as well as several driver characteristics (age, gender, driving experience).

Regarding the effect of distraction on driving performance, conversation with the passenger was not found to have a statistically significant effect, indicating that drivers do not change their driving performance while conversing with a passenger compared to undistracted driving. On the other hand, the negative sign in the variable "cell phone use" indicates that the effect of cell phone on driving performance is definitely negative.

Regarding driver characteristics, several parameters such as age, gender, and experience have a significant impact on the final statistical model, indicating that driver characteristics play a crucial role in overall driving performance. More specifically,

Table 3. Estimation results of the driving performance SEM.

	Est.	SE	*t* Value	*P* (>|*z*|)
Latent variable				
Driving Performance				
Average speed	1.000	—	—	—
SD lateral position	−0.085	0.004	−23,909	0.000
Average gear	0.048	0.002	21,887	0.000
Time to line crossing	−0.109	0.005	−19,972	0.000
Regressions				
Driving performance				
Distraction–cell phone	−1.099	0.342	−3.213	0.001
Area–urban	−15.596	0.467	−33.410	0.000
Traffic–low	1.123	0.285	3.943	0.000
Gender–female	−1.154	0.303	−3.802	0.000
Age	−0.155	0.027	−5.755	0.000
Experience	0.083	0.032	2.630	0.009
Summary statistics				
Minimum function test	305.74			
Degrees of freedom	20			
Goodness-of-fit measure				
SRMR	0.061			

results indicate that driving performance is negatively affected for gender and age parameters. Regarding gender, it is indicated thar females perform worse than males. Furthermore, regarding the effect of age, young drivers are better familiarized with the use of a driving simulator and, as a consequence, their driving performance is better than that of middle-aged and older drivers, especially when distracted by a cell phone. However, this effect of age is partially coutnerbalanced by the fact that driver experience has a postitive impact on driving performance, as indicated by the statistical analysis results.

Regarding road environment, area type is the most important factor affecting driving performance based on the estimation results of the structural equation model. The effect of area type in driving performance is explained by the fact that the more complex road environment in urban areas has a negative effect on overall performance, whereas in rural areas, drivers achieve more stable driving behaviors. Furthermore, traffic conditions also influence driving performance because the variable "low traffic" has a positive sign in the model. This is probably explained by the fact that in high traffic, the complicated road environment including many interactions between vehicles has a negative effect on driving performance.

Discussion

The present study had 2 main objectives. The first was to investigate whether latent model analysis through a structural equation model can be implemented on driving simulator data in order to define an unobserved driving performance variable. Subsequently, the second objective was to investigate and quantify the effect of several risk factors, including distraction sources, driver characteristics, road, and traffic environment, on the overall driving performance and not independent driving performance measures.

Regarding the first objective, considering that driving performance is a multidimensional phenomenon, the results of this analysis allow an important scientific step forward from piecemeal analyses to a sound combined analysis of the interrelationship between several risk factors (including driver distraction) and driving performance. Within the framework of the present research, driving performance is estimated as an unobserved variable defined by 4 different driving simulator parameters that capture a statistically significant part of overall performance.

Focusing on driving performance, a key methodological contribution of the present research concerns the individual simulator parameters that define the unobserved driving performance variable. In general, the large number of parameters that exist indicates that the decision regarding which parameter or set of parameters is used in each research should be guided by the specific research question (Regan et al. 2008). Based on Papantoniou et al. (2017), the most common driving performance categories of parameters include lateral control, longitudinal control, reaction time, gap acceptance, eye movement, and workload measures.

Results of the present research indicate that the selection of the specific measures that define overall performance should be guided by a rule of representativeness between the selected variables, because in the present structural equation model, the unobserved driving performance is defined based on a longitudinal measure (speed), a lateral measure (standard deviation of the lateral position), a reaction time measure (time until the road border line is exceeded), and average gear. The abovementioned categories should be a guide for similar latent model analyses on driving behavior.

With respect to the second objective, considering that the examined statistical analysis is statistically acceptable, quantification of the effect of several risk factors on the overall driving performance is achieved. Based on this, a key issue of the research was the investigation of 2 in-vehicle distraction factors. Results indicate that cell phone use has a statistically significant effect on overall driving performance, which is in line with the literature that cell phone use significantly affects individual driving performance parameters (Haigney et al. 2000; Rakaouskas et al. 2004; Strayer et al. 2003). On the other hand, the present study indicates that drivers do not significantly change their driving performance while conversing with a passenger. Considering that in the literature, conversation with a passenger is reported to either affect (Drews et al. 2008; Laberge et al. 2004; Maciej at al. 2011) or not to affect (Charlton 2009; Yannis et al. 2010) specific driving measures, this finding proves how important it is to define and investigate overall driving performance and not individual parameters.

Following the previous statement, model results indicate that driver-related characteristics play the most crucial role in overall driving performance. Model results showed that driver age, gender, and experience have a statistically significant impact on overall driving behavior. Finally, regarding area and traffic characteristics, results indicate that area type is the most significant factor affecting driver performance because in urban areas, driving performance was negatively affected probably due to the more complex road environment. Based on the above, a very interesting conclusion of the present research that can be extracted only through implementation of this analysis is the development of a driving profile. More specifically, based on the structural equation model, the worst driving performance is achieved by an older, unexperienced female drivers in urban areas with high traffic while talking on a cell phone.

In conclusion, the findings of this study allow a new approach to the investigation of driving behavior in driving simulator experiments and in general. By the successful implementation of structural equation models, driving behavior can be assessed in terms of overall performance and not through individual performance measures. A direct contribution of this methodology relies on the development of a driving profile that has the lowest driving performance, which can be a useful positive reference for road safety stakeholders, especially those that deal with cell phone use while driving.

Finally, the application of this methodology revealed a number of open issues for further research in the interdisciplinary field of driving behavior. Firstly, the present methodological approach could be further developed and applied in more general driving behavior scientific fields. Within this framework, the effect of several other parameters such as fatigue or alcohol can be estimated on the unobserved variables that underlie driving performance. In addition, several other latent variables can be created and examined (i.e., accident risk), depending on the experimental database and the specific research questions.

Funding

This article was implemented within the framework of the "IKY Fellowships of Excellence for Post-Graduate Studies in Greece—Siemens Program."

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