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Risk factors, driver behaviour and accident probability. The case of distracted driving.

Doctoral Dissertation

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To my parents..

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Abstract

The objective of the PhD thesis is the analysis of the effect of road, traffic and driver risk factors on driver behaviour and accident probability at unexpected incidents, with particular focus on distracted driving. For this purpose, a large driving simulator experiment took place in which 95 participants were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in different road (urban/rural) and traffic conditions (high/low). Then, within the framework of an advanced statistical methodology, latent analysis through a sequence of four Structural Equation Models allowed to go well beyond the piecemeal analyses of driving performance measures to a sound combined analysis of the interrelationship between risk factors, driving performance, driver error and accident probability at unexpected incidents. Results indicate that more likely to commit driving errors are young or old female drivers at urban areas while more likely to be involved in an accident at an unexpected incident are female drivers in low traffic conditions while talking on the cell phone.

Περίληψη

Στόχος της διδακτορικής διατριβής είναι η ανάλυση της επιρροής χαρακτηριστικών του οδηγού και του οδικού περιβάλλοντος στην οδηγική συμπεριφορά και την πιθανότητα ατυχήματος σε μη αναμενόμενο συμβάν, με έμφαση στην απόσπαση της προσοχής του οδηγού. Για το σκοπό αυτό, πραγματοποιήθηκε πείραμα σε προσομοιωτή οδήγησης κατά τα οποίο 95 συμμετέχοντες οδήγησαν υπό διαφορετικές συνθήκες απόσπασης της προσοχής (κινητό τηλέφωνο, συνομιλία με συνεπιβάτη), εντός/εκτός κατοικημένης περιοχής σε χαμηλό/υψηλό κυκλοφοριακό φόρτο. Στη συνέχεια, στο πλαίσιο της ανάλυσης λανθανουσών μεταβλητών, αναπτύχθηκε μια αλληλουχία τεσσάρων Δομικών Μοντέλων Εξισώσεων που επέτρεψε τη συνολική συνδυαστική ανάλυση της επιρροής των εξεταζόμενων παραγόντων κινδύνου απευθείας στην οδηγική επίδοση, το οδηγικό λάθος και την πιθανότητα ατυχήματος σε μη αναμενόμενο συμβάν. Τα αποτελέσματα υποδεικνύουν ότι πιο πιθανό να υποπέσουν σε οδηγικό λάθος είναι νέες ή ηλικιωμένες γυναίκες οδηγοί εντός κατοικημένης περιοχής ενώ πιο πιθανό να εμπλακούν σε ατύχημα σε μη αναμενόμενο συμβάν είναι γυναίκες οδηγοί, σε χαμηλό κυκλοφοριακό φόρτο ενώ μιλούν στο κινητό τηλέφωνο.

Extended abstract

The objective of the present PhD thesis is the **analysis of the effect of road, traffic and driver risk factors on driver behaviour and accident probability**, with particular focus on distracted driving. For this purpose, a specially developed methodology is implemented which consists of **4 discrete steps**:

- The first step concerns a comprehensive literature review fully covering the research topics examined.
- In the second step a methodological review is taking place regarding driving performance measures and statistical analysis techniques.
- In the third step, a large driving simulator experiment is carefully designed and implemented.
- In the fourth step an advanced statistical analysis methodology is developed including four different types of analyses.

Beginning with the **first step**, an extensive literature review is carried out, investigating in a comprehensive way the research topics **topics** examined: driving behaviour, driver distraction and its assessment methods, driving simulator characteristics as well as driving simulator studies on driver distraction.

A major part of the literature review consisted of an exhaustive review on **driving simulator studies on driver distraction** indicating that although simulator studies on driver distraction provide useful insights into how driver, vehicle, and roadway characteristics influence distracted driving behaviour and safety, the design and implementation of such experiments is very often inconsistent and they do not always conform to experimental design principles. On the basis of the **comparative assessment** of these studies, it is found that at the majority of studies, the most common distraction sources examined are cell phone use, conversation with passengers and visual distraction, as well as their comparisons. Most experiments are based on very small samples, limited to rural road environment, with non-explicit (if at all) simulation of ambient traffic. No pattern could be identified as regards the selection of number and duration of trials. Moreover, it is a matter of some concern that often the size of the experiment is not adequately adjusted to the sample size in several studies.

The **second step** of the present PhD thesis concerns the choice of the methodological approach allowing to address in an innovative way the research challenges mentioned above. For this purpose, an additional targeted literature review took place in order to investigate the key driving performance measures examined in driver distraction research as well as the statistical analyses implemented in the scientific field of driver distraction.

Results indicate that while driver distraction is a **multidimensional phenomenon,** which means that no single driving performance measure can capture all effects of distraction and the selection of the examined measure should be guided by the nature of the task examined as well as the specific research questions. However, in the literature different driving performance measures are examined in different studies, most often tackling only specific aspects of driving performance. Consequently, the need for a composite driving performance measure is demonstrated.

The **third step** concerns the design and implementation of a large driving simulator experiment, allowing to address the complex challenhges of this PhD thesis. All individual experiment parts are carefully designed and executed tackling the limitations and needs identified in similar driving simulator experiments reviewed in the previous chapters.

Within this framework, **95 participants** were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in different road (urban/rural) and traffic conditions (high/low). Each participant aimed to complete 12 different driving trials, while in each trial, 2 unexpected incidents were scheduled to occur at fixed points along the drive. The above stages were designed on the basis of parameters and criteria shown to be important in the literature, as well as design principles that were appropriate for the research assumptions and objectives of the present research. After the driving simulator tasks, participants were asked to fill in two questionnaires. The first Questionnaire concerned their driving habits and their driving behaviour while the second was a Self-Assessment Questionnaire that covered aspects related to the driving simulator experience.

In the **fourth step**, the data collected from the driving simulator experiment and the respective questionnaires are analysed by means of an innovative statistical analysis method. The overall statistical method consists of four types of analyses.

- In the first analysis, the large size of the dataset makes the **descriptive analysis** of a large number of variables essential. Within this framework, an overview of all variables which are provided by the driving simulator is provided together with a correlation table. Then, several boxplots are presented investigating the effect of specific driving characteristics such as age, gender, area and traffic conditions on different distracted situations on selected driving performance measures.

- Then, in the framework of the explanatory analysis, the development of **regression models** takes place (general linear models and general linear mixed models) regarding key performance parameters such as average speed, reaction time of drivers at unexpected incidents, lateral position, average headway, speed variability, and lateral position variability. Such models are often used in driver distraction analysis in order to estimate the effect of distraction sources and driving characteristics on specific driving performance parameters and indirectly on driving behaviour and road safety.

- Then, **factor analysis** is implemented, as a first step towards the development of latent variables within the framework of the structural equation models, regarding driving performance and driver errors in order to investigate which observed variables are most highly correlated with the common factors and how many common factors are needed to provide an adequate synthesis of the data.

- Finally in the fourth type of analysis, consisting as the central component of the statistical analysis of the present PhD thesis is taking place focusing to the development and application of structural equation models for the first time in the scientific field of driver distraction. Within the framework of latent analysis, a sequence of four **Structural Equation Models** is developed and applied aiming to investigate the quantification of the impact of driver distraction, driver characteristics as well as road and traffic environment directly on driving performance, driver errors, and accident probability at unexpected incidents.

  The sequence of the **four different structural equation models** developed is described graphically in the next figure (each colour represents a different SEM) and explained below:

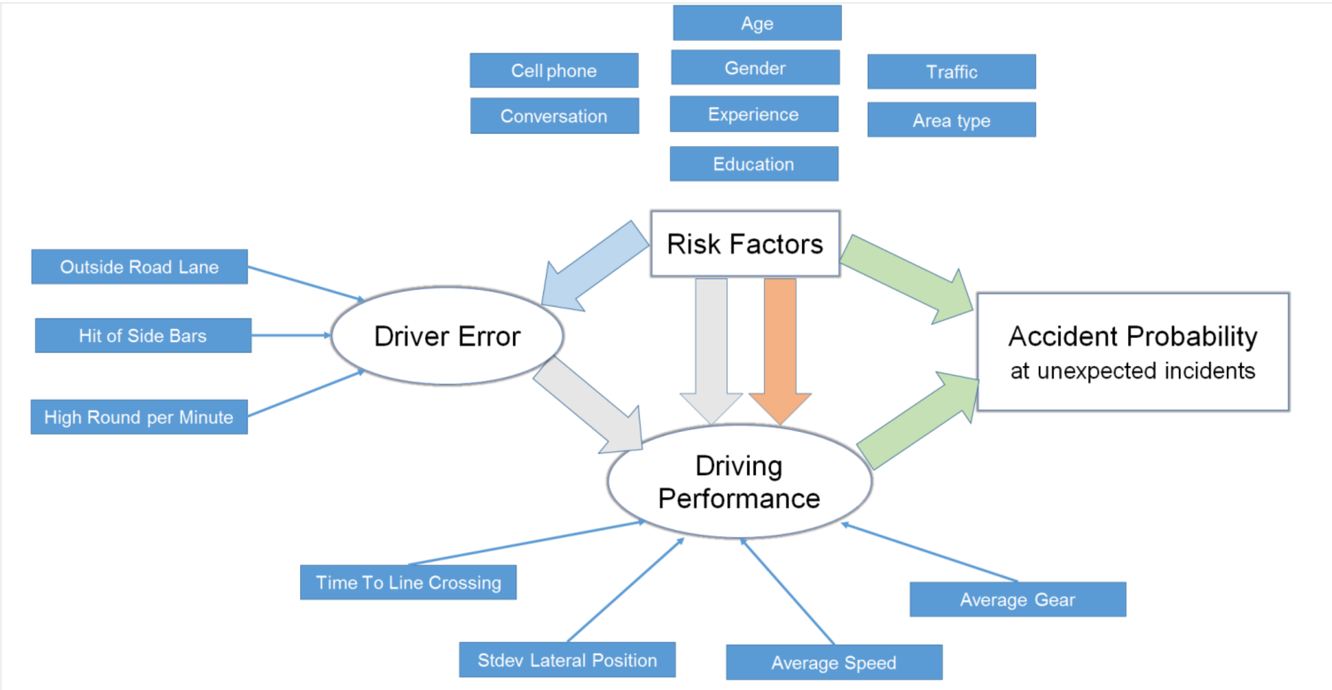

Figure 1 Graphical approach of latent analysis

- In the first SEM (orange arrow), the latent variable reflects the underlying **driving performance** and the objective is the quantification of the impact of distraction, driver characteristics as well as road and traffic environment on driving performance.
- In the second SEM (blue arrow), the latent variable reflects the underlying **driver error** and the objective is the quantification of the impact of distraction, driver characteristics as well as road and traffic environment on driving errors.
- In the third SEM (grey arrow), two latent variables are created regarding **driving performance and driver error** while the objective of this analysis is the quantification of the impact of driving errors, distraction,

driver characteristics as well as road and traffic environment on driving performance.

- In the fourth SEM (green arrow), the latent variable reflects again the underlying driving performance of the participants and the objective is the quantification of the impact of driving performance, distraction, driver characteristics as well as road and traffic environment directly on **accident probability**.

The innovative outcome of the present PhD thesis consists of **four original scientific contributions** as presented here after (see figure 2). It should be noted that the first two scientific contributions refer to the methodological contribution of the research while the third and the fourth are the key research findings of this PhD. The four original scientific contributions are the following:

- A large and rigorous driving simulator experiment
- An innovative statistical analysis methodology introducing latent analysis in driving performance and traffic safety
- The estimation of the combined effect of driver distraction, road, traffic and driver risk factors on driving performance
- The development of a set of risky driving profiles regarding driver errors and accident probability at unexpected incidents

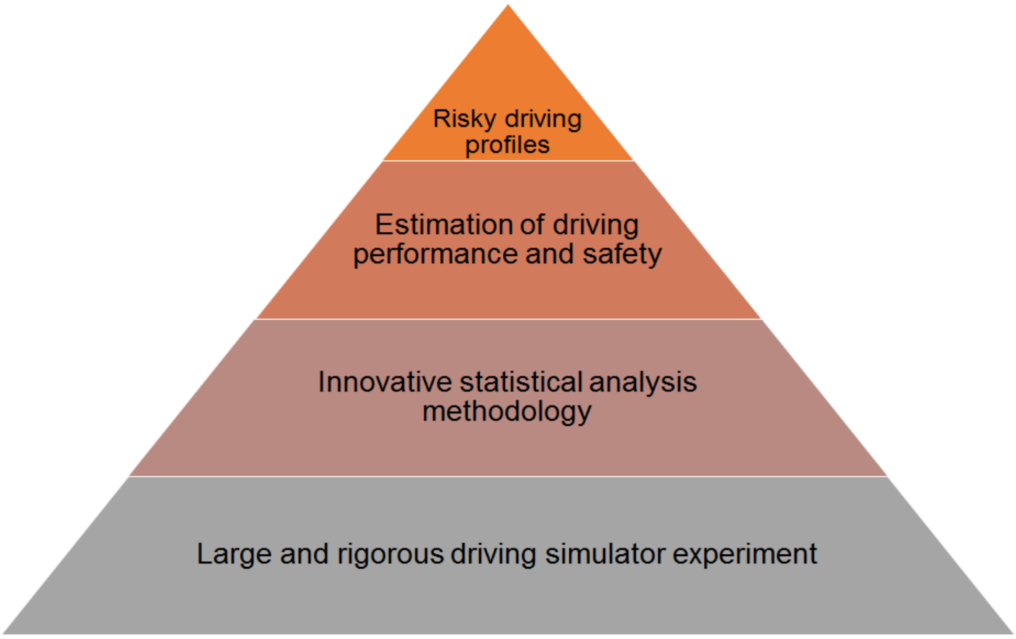

Figure 2 Four original scientific contributions of the PhD

The **first** scientific contribution concerns the design and implementation of **a large and rigorous driving simulator experiment** and consists the basis of the originality of the overall research**.** The design and implementation of this experiment is a central component of the present PhD thesis and it is based on all the respective literature reviews aiming to deal with the majority of limitations that have been noted in the assessment of the examined simulator studies on driver distraction. The basic limitations found in the literature that the present experiment tackled are the following:

- Large and representative sample
- Randomisation of trials
- Adequate practice drive
- Investigation of an optimum number of driving factors

The **second** original scientific contribution of the present PhD thesis concerns the development and application of an **innovative statistical analysis methodology**. More specifically, latent analysis through structural equation models is implemented for the first time in the field of driving performance and traffic safety. Latent analysis allowed an important scientific step forward from piecemeal analyses to a sound combined analysis of the interrelationship between risk factors (including driver distraction), driving performance, driver error and accident probability. For the purpose of this research, two latent variables were created: a) **driving performance** variable reflecting the underlying driving performance of the participants (on the basis of several observed driving measures such as average speed, lateral position variability, average gear, time to line crossing) and b) **driver errors** variable reflecting the driving errors of the participants (on the basis of variables indicating driving errors such as hit of side bars, outside road lanes, high rounds per minute.

The **third original scientific contribution** of the present PhD thesis concerns the estimation of the combined effect of distraction sources, driver as well as road and traffic environment characteristics directly on driving performance.

More specifically, the development and application of the two first structural equation models, allowed the quantification of impact of several risk factors directly on the latent variable which underlines driving performance. Within this analysis, results regarding the effect of driver distraction indicate the different effect on driving performance between cell phone use and conversation with the passenger.

Conversation with the passenger was not found to have a statistically significant effect proving that drivers do not change their overall performance significantly while conversing with a passenger compared to undistracted driving. This finding can be explained by the assumption that the passengers are able to follow the road and traffic conditions and the related workload of the driver and adjust their interventions (distraction) to the driver. On the other hand the effect of cell phone on the overall driving performance was proved to be negative indicating the crucial role of cell phone use on driver behaviour and accident probability.

The change on driving performance of drivers talking on the cell phone is based on two opposing reasons. Firstly, cell phone use while driving distracts drivers in several ways including physical distraction (the driver has to use one hand in order to manipulate the telephone), visual distraction (cell phone use is consisted of prolonged and repeated glances to the cell phone) and cognitive distraction (involves lapses in attention when two mental tasks are performed at the same time). On the contrary, **compensatory distracted behaviour** is occurring which means that drivers while talking on the cell phone feel insecure and change their performance in order to counterbalance the distraction activity. Results confirm the initial hypothesis that the overall balance regarding the effect of cell phone use on driving performance and accident probability is negative.

Finally, the **fourth original scientific contribution** of the present PhD thesis concerns the development of certain risky driving profiles as resulted from the application of the two other latent models regarding **driver errors** as well as **accident probability** at unexpected incidents.

Regarding the effect of distraction on driving errors, neither conversing with a passenger nor talking on the cell phone were found to have a statistically significant impact on driver errors. Based on the finding of the present research the effect of driver characteristics as well as of area type is much higher than the effect of distraction on driving errors. Drivers in the framework of compensatory behaviour are more concentrated when being distracted and seem that they fall in less driving errors. Consequently, **the increased accident risk of distracted driver is due to other factors than their errors**; e.g. inability to cope with the errors of other drivers or other incidents maybe due to increased reaction time.

According to the second latent analysis, accident probability is estimated as the probability for the driver to have an accident at an unexpected incident. The findings of the present PhD thesis indicate that cell phone use has a statistically significant negative effect on accident probability demonstrating that drivers while talking on the cell phone find it difficult to handle an unexpected incident and as a result are more likely to get involved in an accident. This is probably explained by the fact that at unexpected incidents risk compensation strategies of the driver can not counterbalance the higher reaction time due to distraction. On the other hand, drivers (and passengers) self-regulate their driving performance better while conversing with a passenger and as a consequence react better and are less involved in accidents at unexpected incidents.

Summarising the findings from both structural equation models two risky driving profiles can be created as follows:

- **More likely to commit driving errors are young or old female drivers at urban areas.**
- **More likely to be involved in an accident at an unexpected incident are female drivers in low traffic conditions while talking on the cell phone.**

Overall, the proposed methodological approach and statistical techniques of the present research, are proved to significantly improve the potential of the analysis and provide new insights on driver behaviour and safety. The a**dded value** of the methodology, through the consideration of latent variables and the implementation of structural equation models, is found to be useful and promising, revealing new patterns such as the estimation of the effect of risk factors directly on driving performance as well the creation of specific driving profiles.

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1. Introduction

1.1 General

Approximately **1.24 million people die every year** on the world's roads, and another 20 to 50 million sustain nonfatal injuries as a result of road traffic accidents. These injuries and fatalities have an immeasurable impact on the families affected, whose lives are often changed irrevocably by these tragedies, and on the communities in which these people lived and worked (WHO, 2013).

Road accidents are estimated to be the eighth leading cause of fatalities globally, with an impact similar to that caused by many communicable diseases, such as malaria (Lazano et al., 2012) and the leading cause of fatalities for young people aged 15–29 years (Global burden of disease, 2008). Economically disadvantaged families are hardest hit by both direct medical costs and indirect costs such as lost wages that result from these injuries. At the national level, road traffic injuries result in considerable financial costs, particularly to developing economies. Indeed, road traffic injuries are estimated to cost low- and middle-income countries between **1–2 % of their gross national product**, estimated at over US$ 100 billion a year (Jacobs, 2000).

Road accident fatalities have been steadily increasing in many low- and middle income countries, particularly where rapid motorization has not been accompanied sufficiently by **improved road safety strategies**. While better communication could, in theory, result in a reduced need for road travel, and thus lower the exposure to risk of road traffic injuries, in practice the combination of increased road transportation and better and continuous forms of communication may be detrimental to the global road safety picture (WHO, 2013).

Despite the fact that road traffic casualties presented a constantly decreasing trend during the last years, the number of fatalities in road accidents in several countries and particularly in Greece is still unacceptable and illustrates the need for even greater efforts with respect to **better driver behaviour** and increased road safety (OECD, 2008).

A number of factors have been identified as affecting the likelihood of a road traffic injury, and limiting the exposure to these risk factors is critical to the success of efforts to reduce road traffic injuries. For example, there is now a large area of scientific research demonstrating the increased risk of road traffic fatalities and injuries resulting from **human factors**, such as excessive or inappropriate speed, drink–driving, non-use of seat-belts, child restraints or motorcycle helmets and driver distraction (Elvik, 2004; Pedden et al., 2004).

More specifically, **driver distraction** in particular is estimated to be a critical cause of vehicle accidents worldwide with an increasing importance (Yannis, 2013). Although driver distraction can be considered as part of everyday driving, the penetration of various new technologies inside the vehicle, and the expected increase of use of such appliances in the next years, makes the investigation of their influence on the behaviour of drivers and on road safety very essential (Olsen, 2005).

Driver distraction occurs when a driver's attention is, voluntarily or involuntarily, diverted away from the driving task by an event or object to the extent that the driver is no longer able to perform the driving task adequately or safely (Regan et al., 2008). There are four types of driver distraction: physical distraction, visual distraction, auditory distraction, and cognitive distraction. A distracting activity involves one, or more, of these. Furthermore, **driver distraction factors** can be subdivided into those that occur inside the vehicle (cell phone use, conversation with the passenger, music, eating/drinking, etc.) and those that occur outside the vehicle (advertising sings, pedestrians, etc.).

In this framework, several **types of experiments** on assessing driving behaviour and more specifically driver distraction exist, such as naturalistic driving experiments, driving simulator experiments, on road experiments, in-depth accident investigations and surveys on opinion and stated behaviour.

Focusing on **driving simulators**, 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 driver distraction, and numerous studies have been conducted, particularly in the last decade (Regan et al., 2008).

1.2 Objectives and methodology

Within, the above framework, the objective of the present PhD thesis is the **analysis of the effect of road, traffic and driver risk factors on driver behaviour and accident probability**, with particular focus on distracted driving. More specifically, the basic objectives are the following:

- to develop a methodological framework of causes and impacts of driver distraction,
- to design and implement a large driving simulator experiment,
- to develop a unique methodology for the analysis of driver distraction,
- to estimate the effect of distraction directly on driving performance and driver errors,
- to estimate the effect of distraction and driving performance directly on accident probability.

In order to achieve these objectives, **an advanced methodology** is developed which consists of 4 discrete steps:

- The first step concerns an extensive literature review covering several fields of the overall research area.
- In the second step a methodological review is taking place regarding driving performance measures and statistical analysis techniques.
- In the third step, a highly original driving simulator experiment is designed and implemented.
- In the fourth step an innovative statistical analysis methodology is developed including four different types of analysis.

All the above steps of the methodological framework are based on **exhaustive literature review** in the respective areas. Starting with an overview of human factors related to driver behaviour, the cognitive functions related to driving are investigated, allowing to identify the tasks which are critical for safe driving. Then several definitions are provided regarding the terms of driver distraction and driver inattention and their differences are highlighted while the distraction accident mechanism is investigated and the types of driver distraction are analysed. Furthermore, driver distraction factors are categorized whether they are occurring inside or outside the vehicle. Finally, the compensatory behaviour of drivers is investigated in detail as is plays a very critical role in distracted driving performance.

An extended literature review is also carried out regarding all available **experiment types** of assessing driver distraction. More specifically, benefits and limitations are presented regarding naturalistic driving experiments, driving simulator experiments, on road experiments, field tests, in-depth accident investigations and surveys on opinion and stated behaviour. Then, as the present research is based on a large driving simulator experiment, information regarding the validity and fidelity of driving simulators are presented, as well as all specific issues of this type of experiments (sampling, simulator sickness, etc.).

The central part of the literature review is consisted of an exhaustive review on **driving simulator studies on driver distraction**. More specifically, studies reviewed examine driver distraction through driving simulator experiments which were published in scientific journals, concern recent research and report quantitative results. From the results of the review, a comparative analysis assessment of the existing driving simulator experiments is carried out for the basic components of the experiment (distraction source, sample characteristics, experiments design, distraction measures etc.). Finally, a critical assessment and synthesis of the results of existing studies is attempted, allowing for conclusions to be drawn with respect to the strengths and limitations of existing studies and the priority areas for improvement of future experiments.

Based on this literature review, **an advanced methodology** is developed for the investigation of the effect of distraction on driver behaviour and road safety. This specific methodology consists of the following four discrete steps:

In **the first step**, the **conceptual framework** for the investigation of causes and impacts of driver distraction is developed as presented in figure 1.1. According to this conceptual framework, driver distraction is affected by a combination of factors including driver characteristics, road and traffic conditions as well as the distraction source type. A direct consequence of driver distraction is the change in driving behaviour. Consequently, this change of behavior is reflected both in driving performance (e.g. the driver’s speed, the vehicle headway or the vehicle’s position on the road lane) as well as in traffic safety parameters (e.g. the driver’s reaction time and the accident probability in case of an unexpected incident).

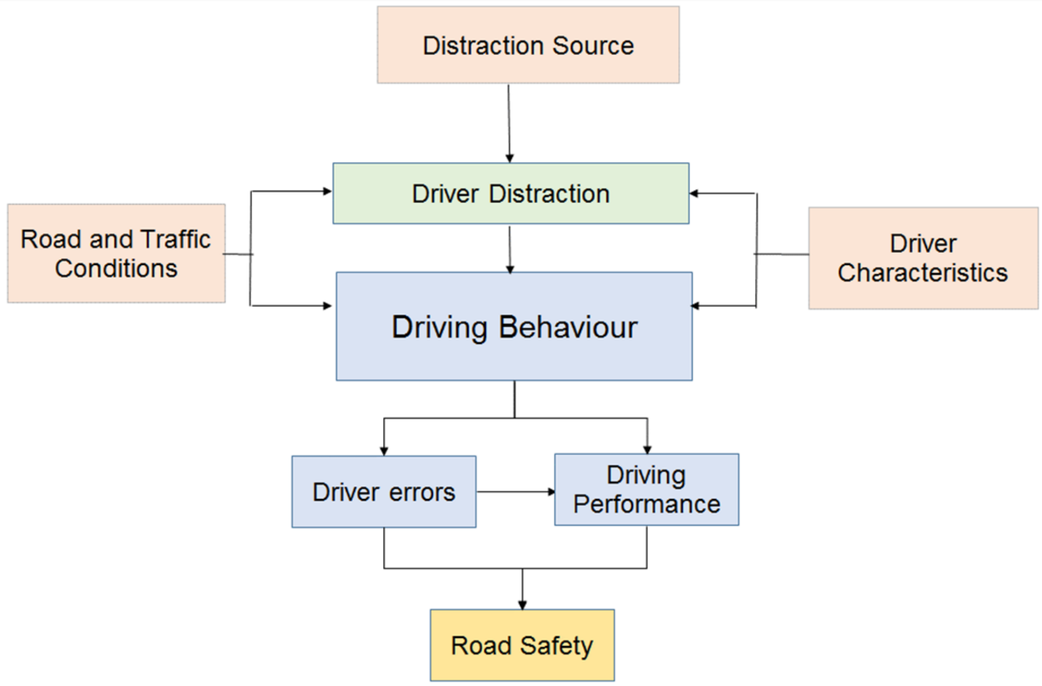

Figure 1.1 Conceptual framework for the analysis of driver distraction

The second step concerns the selection of **key parameters** for the analysis. This selection exploits the findings of the literature review of driving simulator experiments on driver distraction. Based on this literature review and in order to meet the thesis objectives, a selection of the critical parameters took place, both for theoretical and practical reasons.

- **Distraction sources**: Distraction sources selected to be investigated are mobile phone use and conversation with the passenger.
- **Road and traffic conditions** parameters: Driver distraction is investigated in both road (urban / rural area) and traffic (high / low traffic) environments.
- **Driver characteristics**: The experiment sample includes 95 participants from all age groups (young, middle aged and older drivers) and both genders.
- **Driving performance measures**: The driving simulator equipment and software allows for the recording of a large number of variables which will be further analysed in the last steps of the statistical analysis.

The third step concerns the **design** of a large **driving simulator experiment**. The design and implementation of this experiment is a central component of the present PhD thesis and it is based on the respective literature review aiming to deal with the majority of limitations that have been noted in the assessment of the examined simulator studies on driver distraction such as a large and representative sample, the randomization of trials, an adequate practice drive, the investigation of several parameters (road, traffic, distraction source).

In this framework the driving simulator experiment took place at the simulator of the Laboratory of Traffic Engineering of the Department of Transportation Planning and Engineering of the School of Civil Engineering of the National Technical University of Athens in which **95 participants** of all age groups were asked to drive under different road and traffic conditions such as in a rural and urban area, in low and high traffic as well as under different types of distraction (no distraction, cell phone use, conversation with the passenger). Then, participants were asked to fill in two questionnaires. The first questionnaire concerned their driving habits and their driving behaviour while the second was a self-assessment questionnaire that covered aspects related to the driving simulator experience.

The fourth step concerns the analysis methodology development. The large dataset that is collected from the driving simulator experiment as well as the relative questionnaires are analysed by means of a dedicated technique, based again on the limitations and needs of statistical analysis techniques which were extracted from the respective literature review on driver distraction experiments. Two phases of the analysis methodology are implemented.

The first phase concerns the development of **regression models** (general linear models, general linear mixed models) regarding key performance parameters such as average speed, lateral position, reaction time of drivers at unexpected incidents, average headway, speed variability and lateral variability. Such models are often used in driver distraction analysis in order to estimate the effect of distraction sources on specific driving performance parameters and indirectly on driving behaviour and road safety.

The second phase of the analysis methodology, is the central component of the PhD thesis as for the first time **latent variables analysis** is implemented on driver distraction research. This type of analysis is designed 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. In the present analysis, driving performance and accident risk are the unobserved variables which are estimated from specific parameters. The main goal of this attempt is to estimate directly the effect of distraction as well as of road and traffic environment characteristics both on driving performance, driver errors as well as on accident risk.

In order to achieve this target, latent models analysis is implemented including **Factor Analysis** and **Structural Equation Models**. First, factor analysis technique is used in order to select the key driving performance parameters that create a latent variable which reflects the underlying driving performance of the participants as well as a latent variable which reflects driver errors. Next, Structural Equation Models allow the quantification of the impact of driver distraction, driver characteristics and road environment **directly** on driving performance and driver errors more advanced structural equation models are implemented and presented regarding accident risk probability

Statistical analysis results allow the estimation of the effect of **distraction** as well as **road**, **traffic** and **driver risk factors** on driving performance. Furthermore, the estimation of all the above parameters on driver errors and accident probability leads to the development of specific **risky driving profiles** completing the puzzle of the effect of driver distraction on driver behaviour and road safety.

1.3 Structure

The PhD thesis is organized as follows (see also figure 1.1):

Chapter 2 constitutes the main part of the entire **literature review** and is consisted of several parts. Starting with a review of driving behaviour parameters, an overview of human factors related to driver behaviour is presented as well as cognitive functions critical for safe driving. Next, with regard to driver distraction, the definition of it, the types of distraction, the most common distracted driving factors as well as the distraction accident mechanism are provided, while the compensatory behaviour of drivers is analysed. In the next step, an extended literature review is carried out regarding all available experiment types of assessing driver distraction including benefits and limitations of each type. Then, as the present research is based on a large driving simulator experiment, information regarding the validity and fidelity of driving simulators are presented, while the phenomenon of simulator sickness is explored. Proceeding to the central part of the literature review, an exhaustive review on driving simulator studies on driver distraction takes place followed by a comparative analysis assessment of the existing driving simulator experiments, allowing for conclusions to be drawn with respect to methodological and statistical limitations of existing studies and setting the key research questions for the present PhD thesis.

Chapter 3 describes the methodological approach of the present research. In the beginning, the most common **types of measures** are recorder including lateral control, longitudinal control, reaction time, gap acceptance, eye movement and workload measures. Then, the theoretical background for the selected statistical analysis is provided and a synopsis sets the key methodological research questions.

In **Chapter 4**, all steps of the **driving simulator experiment** are presented including the experiment design, driving scenarios, procedure of the experiment, behaviour and memory surveys, data base and processing as well as sample characteristics. More specifically, first the overview of the experiment is presented including information regarding the driving simulator, the exclusion criteria and the simulator sickness. Next, all different driving scenarios are analytically presented while in the procedure of the experiment, the different phases of the experiment are presented and special attempt is given to familiarise with the simulator. Finally, two questionnaires (Driving behaviour Questionnaire and Self-Assessment and Memory) are presented, details regarding the large data base and the processing are recorded while sample characteristics are provided.

Chapter 5 presents the **results** of the modeling methodology that has been developed in order to achieve the objectives set out in this PhD thesis. The methodology consists of several steps as follows. In the first step, in order to analyze the large dataset, a descriptive analysis took place. Then, general linear mixed models were developed in order to estimate the effect of distraction, driver, road and traffic risk factors on selected key driving performance parameters. In the third step, factor analysis took place aiming to estimate the key driving simulator variables that underline driving performance and driver errors. Finally, structural equation models were implemented in order to investigate all the critical risk factors that affect driving performance and driving errors and then to correlate for the first time driving performance and driving characteristics with accident probability at unexpected incidents.

In Chapter 6, a **synthesis** of the results takes place answering all the research questions that have been raised in this PhD dissertation and setting out the scientific contributions of the present research. At last, some future steps for further research in the scientific field of driving behaviour and driver distraction are presented.

1.4 Acknowledgment

This PhD thesis has exploited work performed in two research projects carried out by the Department of Transportation Planning and Engineering of the School of Civil Engineering of the National Technical University of Athens, within the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF), co-financed by the European Union (European Social Fund – ESF) and Greek national funds. The two research projects concerned:

- "**DISTRACT** - Causes and impacts of driver distraction: a driving simulator study" within the Research Program THALES.
- "**DriverBRAIN** - Performance of drivers with cerebral diseases at unexpected incidents" within the Research Program ARISTEIA.

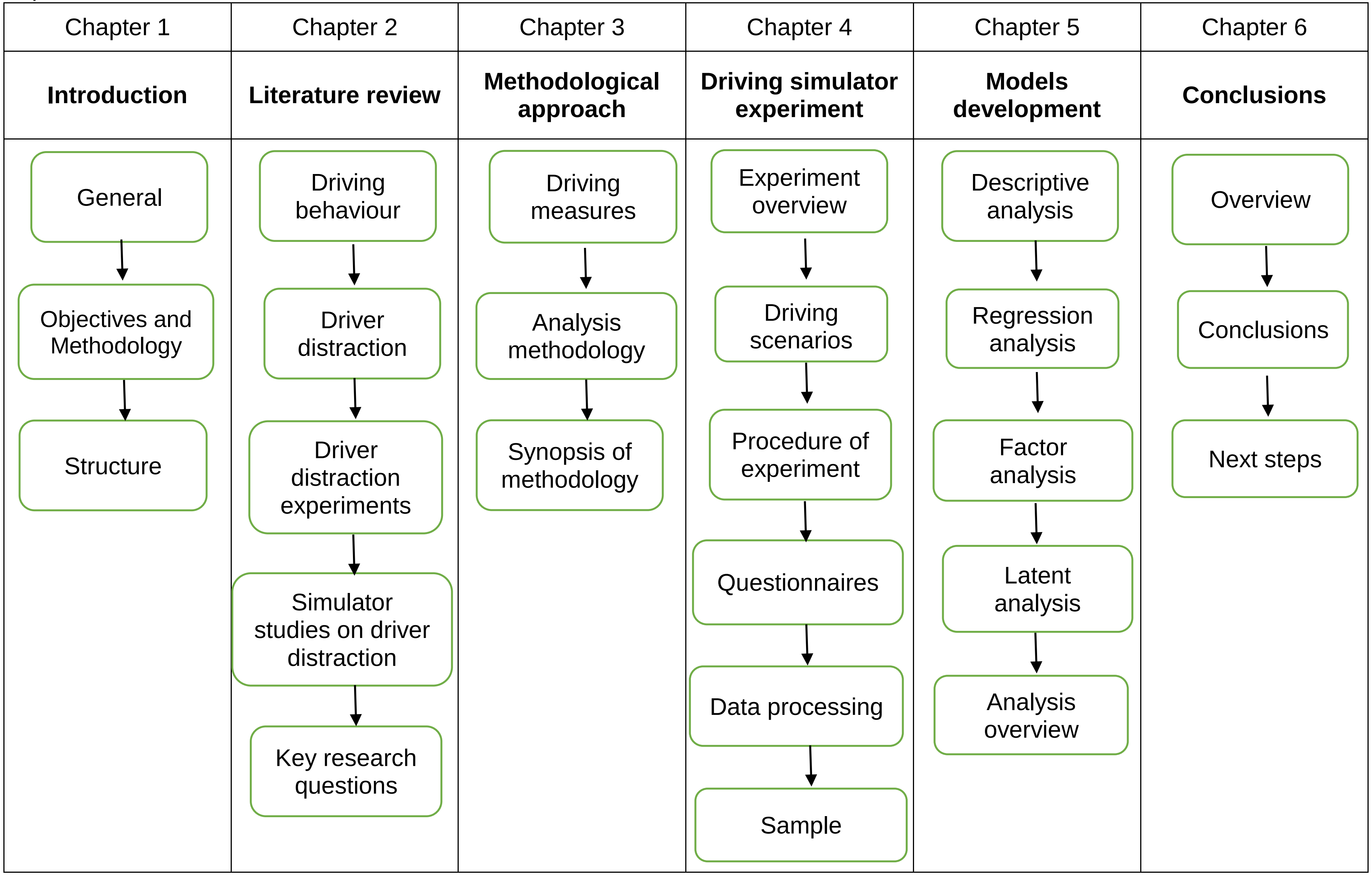

Figure 1.2 Structure of the PhD thesis

2. Literature review

Chapter 2 constitutes the main part of the entire literature review and consists of several parts. It starts with a review of **driving behaviour** parameters, in which an overview of human factors related to driver behaviour as well as cognitive functions critical for safe driving are presented and analysed.

Several definitions are then provided regarding the terms of **driver distraction** and driver inattention. The differences of these two terms are highlighted while the distraction accident mechanism is investigated and the types of driver distraction are analysed. Furthermore, driver distraction factors are categorized whether they are occurring inside or outside the vehicle. Finally the compensatory behaviour of drivers is deeply investigated.

In the next step, an extended literature review is carried out regarding all available **experiment types** of assessing driver distraction. More specifically, benefits and limitations are presented regarding naturalistic driving experiments, driving simulator experiments, on road experiments, in-depth accident investigations and surveys on opinion and stated behaviour. Next, considering that the present research is based on a large driving simulator experiment, information regarding the validity and fidelity of driving simulators are provided, while the phenomenon of simulator sickness is explored.

The central part of the literature review is consisted of an exhaustive review on **driving simulator studies on driver distraction**. More specifically, studies reviewed examine driver distraction through driving simulator experiments which were published in scientific journals, concern recent research and report quantitative results. The distraction sources examined include cell phone use, conversation with passenger, music, radio, in vehicle information systems, eating, drinking, smoking, alcohol, visual distraction as well as advertising signs. From the results of the review, a comparative analysis assessment of the existing driving simulator experiments is carried out for basic components of the experiment (distraction source, sample characteristics, experiments design, distraction measures etc.).

Finally, a **critical assessment** and synthesis of the results of existing studies is attempted, setting the key experimental research parameters of the present research and allowing for conclusions to be drawn.

2.1 Driving behaviour

Road accidents constitute a major social problem in modern societies, accounting for more than 1.2 million fatalities in 2013 worldwide (WHO, 2014), 25.000 in Europe and 879 in Greece (EL.STAT., 2014). Furthermore, **human factors** are the basic causes in 65-95% of road accidents (Sabey and Taylor, 1980; Salmon et al., 2011; Treat, 1980). The remaining factors include the road environment (road design, road signs, pavement, weather conditions etc.) and the vehicles (equipment and maintenance, damage etc.), as well as combinations of these three contributory factors.

In this section, human factors in driver behaviour are analysed with emphasis on driver distraction while cognitive functions critical for safe driving are discussed.

2.1.1 Human factors in driving behaviour

Human factors involve a large number of specific factors that may be considered as accident causes, including: (Department for Transport, 2008):

- Driver injudicious action (speeding, traffic violations etc.)
- Driver error or reaction (loss of control, failure to keep safe distances, sudden braking etc.)
- Behaviour or inexperience (aggressive driving, nervousness, uncertainty etc.)
- Driver distraction (cell phone use, conversation with passenger etc.)
- Driver impairment (alcohol, fatigue etc.)

Figure 1 shows the percentage of accidents in which each **contributory factor** was reported in Great Britain in 2008, including a breakdown by accident severity. Four of the five most frequently reported contributory factors were some kind of driver error or reaction, which includes “failed to look properly” and “failed to judge other person’s path or speed”. Impairment or distraction factors account totally for 12% of all contributory factors.

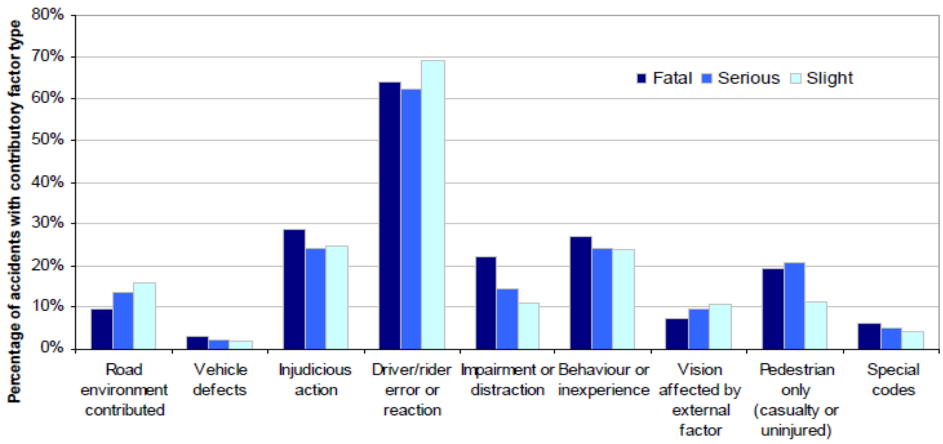

Figure 2.1 Road accident contributory factors by accident severity (Department for transport, 2008)

Moreover, in Table 2.1 the results are further analyzed in terms of the number of accidents reported in Great Britain for the contributory factor "impairment or distraction". The accidents are classified by severity and divided as per the type of impairment or distraction involved. It can be seen that distraction contributory factor account for less than 30% of all **"impairment and distraction"** factors.

Table 2.1 Number of accidents for contributory factor "impairment or distraction" (Department for transport, 2008)

	Fatal Accidents		**Serious Accidents**		**Sight Accidents**		**All Accidents**	
	Number	%	Number	%	Number	%	Number	%
Impairment of distraction	**479**	**22%**	**2.924**	**14%**	**12.159**	**11%**	**15.562**	**12%**
Impaired by alcohol	237	11%	1.485	7%	5.036	5%	6.758	5%
Impaired by drugs (illicit or medicinal)	56	3%	207	1%	424	0%	687	1%
Illness or disability, mental or physical	90	4%	402	2%	1.356	1%	1.848	1%
Distraction in vehicle	**69**	**3%**	**339**	**2%**	**2.406**	**2%**	**2.814**	**2%**
Fatigue	64	3%	374	2%	1.374	1%	1.812	1%
Distraction outside vehicle	**34**	**2%**	**219**	**1%**	**1.650**	**2%**	**1.903**	**1%**
Uncorrected, defective eyesight	18	1%	44	0%	163	0%	225	0%
Driver using mobile phone	16	1%	60	0%	247	0%	323	0%
Not displaying lights at night or in poor visibility	4	0%	92	0%	321	0%	417	0%
Cyclist wearing dark clothing at night	9	0%	84	0%	365	0%	458	0%

Furthermore, according to Petridou and Moustaki (2000), human factors may include factors that reduce the driver's capability to meet traffic contingencies, in long or short term, or factors that modulate risk taking while driving (Table 2.2).

Table 2.2. Human factors affecting driver behaviour and safety (Petridou and Moustaki, 2000)

	Reduce capability to meet traffic contingencies
Long – Term	Inexperience Old age Disease and Disability Accident proneness Alcoholism and drug abuse
Short - Term	Drowsiness, fatigue Acute alcohol intoxication Short – term drug effects Binge eating Acute psychological stress Temporary distraction
	Modulate risk taking while driving
Long – Term	Overestimation of capabilities, 'macho' attitude Habitual speeding Habitual disregard of traffic regulations Indecent driving behaviour Non-use of seat belt or helmet Inappropriate sitting while driving Accident proneness Alcoholism
Short - Term	Moderate ethanol intake Psychotropic drugs Motor vehicle crime Suicidal behaviour Compulsive acts

Old age, disease and disability are among the key factors which may result in reduced capability to drive safely. **Older drivers** are more likely to have cognitive, motor and sensor-perceptual deficits that could affect their driving performance even in the absence of overt disease. The elderly driver, however, is often able to compensate for minor functional declines by adjusting driving behaviour. Nevertheless, several diseases and disabilities may reduce older driver's capability of driving.

2.1.2 Cognitive functions critical for safe driving

Driving is a complex task that requires possessing sufficient cognitive, visual and motor skills. The driver must have adequate motor strength, speed and coordination. Perhaps more importantly, higher **cognitive skills** including concentration, attention, adequate visual perceptual skills, insight and memory need to be present. Higher cortical functions required for driving include strategic and risk taking behavioural skills, which involve the ability to process multiple simultaneous environmental cues in order to make rapid, accurate and safe decisions. The task of driving requires the ability to receive sensory information, process the information, and to make proper, timely judgments and responses (Waller, 1980; Freund et al., 2005).

Cognitive functions related to driving may be categorized into the following six **neuropsychological** domains (Reger et al., 2004):

- mental status–general cognition
- attention–concentration
- executive functions
- language–verbal functioning
- visuospatial skills
- memory

Laberge (1997) made a distinction between three aspects of attention: selection, preparation and maintenance. Selection is a rapid process, which typically is used in search tasks to separate a target from distractors. Preparation is a slower process, which occurs when an individual recruits attention in order to concentrate on an upcoming stimulus without being distracted by irrelevant events. Maintenance of attention is the ability to allocate attention toward a stimulus source over a relatively long duration of time. Several researchers (Parasuraman and Nestor, 1991; Duchek et al., 1998) have argued that selective attention is most specific to driving deficits in older drivers, or in drivers with some pathological condition (e.g. dementia). Identifying important information in the environment while ignoring irrelevant information may be important driving skills.

Drivers may compensate for declines in selective attention by driving more slowly, thereby allowing more time for information processing (Hakamies and Blomqvist, 1993). However, safe driving requires that a number of complex decisions are made while selecting attention between concurrent tasks, in a limited time frame.

The importance of **visuoconstructional skills** to driving has been highlighted in several studies (Johansson and Lundberg, 1997) Safe drivers must position the car accurately on the road and manoeuvre the vehicle correctly. Visuoconstructional skills are also important to judging distances and predicting the development of traffic situations. Visuoconstructional deficits are commonly observed in older drivers, especially with early dementia, represented by a disturbance in formative activities such as assembling, building, and drawing, so that the individual is unable to assemble parts in order to form a whole (Benton, 1994).

Although attention and visuocontructional skills represent a necessary foundation of driving ability, these competencies, similarly to all cognitive skills, require adequate supervision by the executive system of the brain (Royall, 2000). **Executive abilities** are thought to be important for dual task coordination, and necessary for car positioning, maintaining safe distances, driving on roundabouts, journey planning, estimating risk, and for adapting behaviour such as adjusting speed to traffic conditions (Radford and Lincoln, 2004).

2.2 Driver distraction

Driver distraction constitutes a particular human factor of road accident causation. **Driver distraction** is generally 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" (Regan et al., 2008). More specifically, driver distraction involves a secondary task, distracting driver attention from the primary driving task (Donmez et al., 2006; Sheridan, 2004) and may include four different types: physical distraction, visual distraction, auditory distraction and cognitive distraction.

The following sections present several definitions with regard to the terms of driver distraction and driver inattention. They highlight their differences they investigate the distraction accident mechanism and they analyse the types of driver distraction. Then, driver distraction factors are categorized whether they are occurring inside or outside the vehicle while the compensatory behaviour of drivers is investigated in detail as it plays a very critical role in distracted driving performance.

2.2.1 Driver distraction definition

The use of **different**, and sometimes **inconsistent,** definitions of driver distraction can create a number of problems for researchers and road safety stakeholders. First, the lack of consistent definitions across studies can make the comparison of research findings difficult or even impossible, as even seemingly similar studies can be examining slightly different concepts and measuring different outcomes. Inconsistent definitions can also lead to different interpretations of road accident data and, ultimately, to different estimates of the role of distraction in accidents. These issues highlight the need to develop a common, generally accepted definition of driver distraction.

Driver distraction is part of the broader category of **driver inattention**. What distinguishes distracted driving from inattentive driving is the presence of a specific event or activity that triggers the distraction (Regan et al., 2005).

Conversely with driver distraction, very few definitions of driver inattention exist in the literature, and those that do, like driver distraction, vary in meaning. Lee et al. (2008) for example, define driver inattention as "diminished attention to activities critical for safe driving in the absence of a competing activity". In this framework, Regan et al. (2005) proposed that: "**Driver Inattention**" means insufficient or no attention to activities critical for safe driving and "Driver distraction" is just one form of driver inattention, with the explicit characteristic of the presence of a competing activity.

Summarising the above, Regan et al., 2005, defined "**Driver distraction as a diversion of attention away from activities critical for safe driving toward a competing activity".**

2.2.2 Types of driver distraction

There are four types of driver distraction: physical distraction, visual distraction, auditory distraction, and cognitive distraction. A distracting activity involves one, or more of these. The act of operating a hand-held cell phone for example, may involve all four types of distraction (Breen, 2009)

- **Physical distraction** when the driver has to use one or both hands to manipulate the telephone to dial a number, answer or end a call instead of concentrating on the physical tasks required by driving (Young et al., 2003).

- **Visual distraction** is caused by the amount of time that the drivers' eyes are on the cell phone and off the road or, while talking over the telephone, looking at the road but failing to see. The use of cell phones that display visual information (e.g. reading SMS) while driving will further distract drivers' visual attention away from the road (Dragutinovits and Twisk, 2005).

- **Auditory distraction** can occur when the driver is startled by the initial ringing of the telephone or by the conversation itself.

- **Cognitive distraction** involves lapses in attention and judgment. It occurs when two mental tasks are performed at the same time. Conversation competes with the demands of driving. Listening, alone, can reduce activity in the part of the brain associated with driving by more than a third (Ma et al., 2008). The extent of the negative effects of cell phone use while driving depends on the complexity of both cell phone conversations and of driving situation. The more difficult and complex the conversation, the stronger its effects on driving performance. The more difficult the driving situation, the more impact the telephone conversation can be expected to make (SWOW, 2008).

2.2.3 Distracted driving factors

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). Although different studies report different specific distraction factors in each category, one of the most complete and comprehensive approaches is presented in table 2.3 (Regan et al., 2005).

Table 2.3 Driver distraction sources by category (in-vehicle / external)

Driver distraction sources	
In-vehicle	**External**
Passengers	Traffic control
Communication	Other vehicle
Entertainment systems	Seeking location / destination
Vehicle systems	Pedestrian / cyclist
Eating / drinking	Accident / incident
Smoking	Police / Ambulance / Fire brigade
Animal / insect in the vehicle	Landscape / architecture
Coughing / sneezing	Animal
Stress	Advertising signs
Daydreaming	Road signs and markings
	Sun / other vehicle lights

Driver distraction factors that occur **inside the vehicle** seem to have greater effect on driver behaviour and safety. Horberry et al. (2006) confirm that in-vehicle distraction sources have a more important effect on driver performance, compared to the increased complexity of the stimuli received from the road and traffic environment. Moreover, a couple of studies report that external distraction factors are less than 30% of the total distraction factors (Stutts et al., 2001; Kircher, 2007). Other studies specify that **external** distraction factors account for less than 10% of all distraction factors (Sagberg, 2001; MacEvoy et al., 2007).

It is noted that a recent exhaustive research conducted in the Great Britain, in which the effect of more than 70 road accident **contributory factors** was examined, driver distraction was found to be a contributory factor in only 3% of all accidents. Out of this 3%, in-vehicle distraction sources accounted for 2%, whereas external distraction sources accounted for only 1% of all accident contributory factors (Department for Transport, 2008).

Moreover, a study carried out by Patel et al. (2008) examined perceived qualitative characteristics of 14 driver distractions. Survey participants were asked to complete a questionnaire in which ranked a list of distractions according to certain criteria. Table 2.4 shows the **mean perceived risk** ratings of each of the 14 driver distractions. The highest perceived risk ratings were associated with the use of cell phones, followed by 'looking at a map or book' and 'grooming'. The lowest perceived risk ratings were associated with 'listening to music', 'talking to passengers' and 'looking at road signs'. It is noted that advertising signs and landscape have a non-negligible perceived risk level as external distraction sources.

Table 2.4 Perceived risk associated with driver distraction
(Patel et al., 2008)

Driver Distraction Hazard	Risk rating	Lower limit	Upper limit
Listening to music	3.3	1.2	4.8
Talking to passengers	3.8	2.0	5.0
Looking for/at road signs	4.2	3.0	6.0
Satellite navigator use	4.6	3.0	6.0
Hands-free kit use	4.7	3.0	6.0
Looking at Landscape	5.2	3.0	7.0
Adjusting device	5.3	4.0	7.0
Smoking	5.3	3.0	7.0
Looking at advertising sign	5.7	4.0	8.0
Eating or drinking	6.3	5.3	8.0
Looking for object	7.4	6.0	9.0
Grooming/make-up	8.5	8.0	10.0
Looking at a map or book	8.5	8.0	10.0
Mobile phone use	8.6	8.0	10.0

More analytical results on the actual relative importance of different distraction factors was sought in the reports of the 100-Car naturalistic driving study carried out in the USA. Table 2.5 shows results on the odds ratio (i.e. increased risk) of engaging in various secondary distracting tasks over "just driving" (statistically significant results are in bold). A significant odds ratio indicates an important increase in risk associated with that activity.

Table 2.5 Odds ratio for secondary task
(NHTSA, 2008)

Type of Secondary Task	Odds Ratio
Reaching for a moving object	8.82
Insect in vehicle	6.37
Reading	3.38
Applying makeup	3.13
Dialling hand-held device	2.79
Inserting/retrieving CD	2.25
Eating	1.57
Reaching for non-moving object	1.38
Talking/listening to a handle-held device	1.29
Drinking from open container	1.03
Other personal hygiene	0.70
Adjusting the radio	0.50
Passenger in adjacent seat	0.50
Passenger in rear seat	0.39
Child in rear seat	0.33

These results suggest that "reaching for a moving object" is associated with the highest risk, increased by more than eight times compared to just driving, followed by "reading' and 'applying make-up", increasing risk by more than 3 times. Subsequently, the use of **cell phone** is associated with 2.8 times increased accident risk.

2.2.4 Distraction accident mechanism

Driver distraction may have an impact to **driver attention** (i.e. hands-off the wheel, eyes-off the road), **driver behaviour** (i.e. vehicle speed, headway, vehicle lateral position, driver reaction time) and **driver accident risk**.

The key elements affecting the distracted driving accident risk mechanism are the following:

- **Attentional demands**: The amount of resources required to perform the distraction task.
- **Exposure**: How often and when drivers engage in the task. Driver strategies (if any) to compensate for distraction.
- **Risk compensation**: Can the additional mental or motor workload be counterbalanced by adjusting driving behaviour?

More specifically, a decrease in speed and an increase in the distance from the central axis of the road are often observed during distracted driving, and these might be considered beneficial for road safety. However, they cannot always counter-balance the driver's distraction, which leads to increased reaction times, and eventually increased accident probability, especially at unexpected incidents. This complex distracted driving accident **risk mechanism** is illustrated in Figure 2.2.

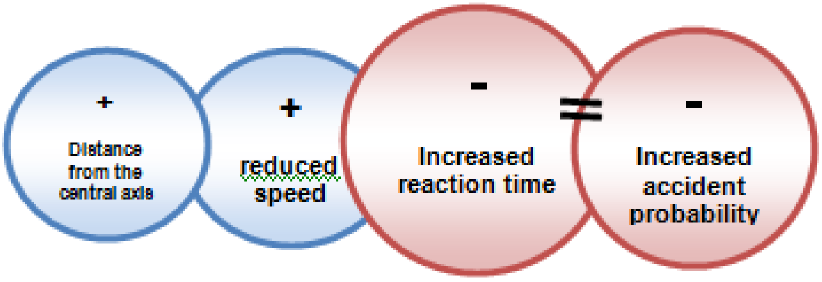

Figure 2.2 Distracted driving mechanism

2.2.5 Compensatory behaviour

One fundamental question regarding the effect of distraction on driving performance is whether and how drivers **self-regulate** their driving to compensate for any decrease in attention to the driving task. Surprisingly, very little research has been conducted to specifically address this issue. Rather, research has focused on identifying the particular performance impairments associated with distraction activities (Haigney et al., 2000).

It is important to recognize, however, that not all changes in driving performance associated with non-driving tasks are indicative of driver impairment, and research suggests that drivers do engage in a range of conscious and unconscious **compensatory behaviours** in order to attempt to maintain an adequate level of safe driving (Poysti et al., 2005).

Compensatory or adaptive behaviour can occur at a number of levels ranging from the **strategic** (e.g., choosing not to use a cell phone while driving) to the **operational** level (e.g., reducing speed) (Alm and Nilsson, 1995; Lamble et al., 2002). At the highest level, drivers can choose to moderate their exposure to risk by choosing not to engage in a potentially distracting task while driving. Research has shown, for example, that older drivers' driving performance is impaired to a greater degree than younger drivers when using a cell phone and this results in compensatory behaviour at the highest level; many older drivers choose not use a cell phone while driving (Alm and Nilsson, 1995; Lamble et al., 2002).

At the operational level, several studies have shown that drivers attempt to reduce workload and **moderate** their exposure to **risk** while interacting with in-vehicle devices. They do this through a number of means: decreasing speed (Alm and Nilsson, 1990; Burns et al., 2002; Haigney et al., 2000; Rakauskas et al., 2004), increasing inter-vehicular distance (Jamson et al., 2004; Strayer and Drews, 2004; Strayer et al., 2003), changing the relative amount of attention given to the driving and non-driving tasks in response to changes in the road environment (Brookhuis et al., 1991; Chiang et al., 2001), and accepting a temporary degradation in certain driving tasks (Brookhuis et al., 1991; Harbluk et al., 2002).

Several on-road and simulator studies have found that drivers tend to **decrease** their **mean speed** when engaging in a secondary task (Haigney, 2000; Rakauskas, 2004; Chiang et al., 2001). The observed reductions in speed while engaging in a secondary task could be the result of drivers modifying their performance goals and accepting a sub-optimal level of driving performance, or the result of drivers simply allocating too much attention to the secondary task and insufficient attention to the primary driving task. Both of these explanations can have road safety implications, resulting from the driver either not allocating sufficient resources to the driving task and, hence, any potential hazards in the road environment, or because the driving performance standard that they are willing to accept may be below that needed for safe driving in certain situations.

An **increase** in **following distance** is another compensatory behaviour that has been displayed by drivers while they are interacting with in-vehicle devices (Strayer et al., 2003; Jamson et al., 2004; Yannis et al., 2010). Interestingly, although the drivers in all three studies attempted to compensate for their reduced attention to the roadway by adopting longer following distances, in many cases this increased headway was often inadequate to avoid collisions with other road users.

Another compensatory behaviour drivers have been found to engage in when interacting with in-vehicle devices is to change the amount of **attention** they allocate to the primary and secondary tasks at any given time in response to changes in the driving environment (Chiang et al., 2004; Brookhuis et al., 1991). It thus, appears that the amount of attention drivers are willing to allocate to the performance of a secondary task is situation dependent and may change across driving environments and task types.

2.3 Types of assessing driver distraction

In this section, an extended literature review is carried out regarding all available **experiment types** of assessing driving behaviour. More specifically, benefits and limitations are presented regarding naturalistic driving experiments, driving simulator experiments, on road experiments, in-depth accident investigations and surveys on opinion and stated behaviour. In the end, a comparative assessment of experiments for the assessment driver behaviour is taking place.

2.3.1 On-road experiments

In On-road experiments studies, an instrumented vehicle is equipped with instrumentation to take recordings of a variety of aspects of driving (Rizzo et al., 2002). These technologies include GPS, video-cameras, sensors, accelerometers, computers, and radar and video lane tracking systems. On-road experiments attempt to gain greater insights into the factors that contribute to road user accident risk and the associated accidents factors at specific conditions. These investigations are conducted by trained experts from multiple disciplines to collect as much useful information as possible, to be of maximum benefit in answering current research questions and any that may arise in the future (Wadley et al., 2009; Bowers et al., 2013; Okonkwo, 2009).

On road driving evaluations are generally considered to be the gold standard method for determining driving fitness (Odenheimer et al., 1994; Di Stefano and Mcdonald, 2003) as a large degree of control over the variables that affect driving behaviour occurs. On-road testing, also provides the opportunity to examine driver competency, as drivers perform actual driving activities and includes aspects of driving that may not be easily replicable by other testing means (Ball and Ackerman, 2011).

On the other hand, on road studies can be criticized because they do not collect data over a longer time period and in response to selected interventions, as in more naturalistic settings as in naturalistic driving studies. Another methodological issue is that the studies utilizing instrumented test vehicles typically have at least one researcher present, at the very least, to give navigation directions. On other occasions a second researcher is present to make other observations about the driver's behaviour. However, these types of studies do offer unique data collection opportunities with respect to the concurrent use of multiple methods and are of high cost (Ball and Ackerman, 2011).

2.3.2 Naturalistic driving experiments

Naturalistic Driving is a relatively new research method for the observation of everyday driving behaviour of road users. For this purpose, systems are installed in participants' own vehicles that register vehicle manoeuvres, driver behaviour (such as eye, head and hand manoeuvres) and external conditions. In a Naturalistic Driving study, the participants drive the way they would normally do, in their own car and without specific instructions or interventions. This provides very interesting information about the relationship between driver, road, vehicle, weather and traffic conditions, not only under normal driving conditions, but also in the case of incidents or accidents (SWOW, 2010).

Naturalistic Driving Experiments offer much wider perspectives in understanding normal traffic behaviour in normal everyday traffic situations. Researchers study issues that cannot be investigated in a lab because participants feel as they are not involved in an experiment as there is no experimenter present, there are no experimental interventions or aims that participants can guess and act for. Furthermore, there is the possibility to observe conflicts, near crashes or even actual crashes in real time without potential biases of post-hoc reports. Moreover, a naturalistic study can contribute to clarifying the prevalence of fatigue and distraction amongst drivers and the related accident risk, to clarifying the interaction between road and traffic conditions and road user behaviour, to understanding the interaction between car drivers and vulnerable road users in different circumstances, to specifying the relationship between driving style and vehicle emissions and fuel consumption, and many other aspects of traffic participation that are difficult to study by means of traditional research (Regan et al., 2012).

On the other hand, a first and important **disadvantage** of naturalistic studies is that, by definition, in a naturalistic study there is no experimental control of the various variables that potentially affect the behaviour of the road user. This means that naturalistic studies data results in correlation between particular variables and road user behaviour, but not in unambiguous causal relationships, while traffic incidents are very rare. Secondly, it is generally assumed that in a naturalistic study, drivers behave as they normally do, because after a while they forget that they participate in a study and that they are being observed all the time. There are indeed strong indications that this is what actually happens, but so far, strict scientific proof is lacking. A third related issue is that drivers in the study sample participate on a voluntary basis. Therefore, it cannot be ruled out that there is a self-selection bias and that the volunteers differ in relevant aspects from non-participants. Hence, the observed behaviour may not always be representative of the whole population. However, the direction and the approximate size of such a bias can be established and taken into account by using carefully designed background questionnaires (Van Schagen et al., 2011).

2.3.3 Driving simulator experiments

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.

More specifically, driving simulators have a number of **advantages** over on-road studies. First they provide a safe environment for the examination of various issues using multiple-vehicle scenarios, where the driver can negotiate very demanding roadway situations. Second, greater experimental control can be applied in driving simulators compared with on-road studies, as they allow for the type and difficulty of driving tasks to be precisely specified and any potentially confounding variables, such as weather, to be eliminated or controlled for. Third, the cost of modifying the cockpit of a simulator to allow for the evaluation of new in-vehicle systems may be significantly less than modifying an actual vehicle. Finally, a large range of test conditions (e.g., night and day, different weather conditions, or road environments) can be implemented in the simulator with relative ease, and these conditions can include hazardous or risky driving situations that would be too difficult or dangerous to generate under real driving conditions (Papantoniou et al., 2013).

The use of driving simulators as research tools does, however, have a number of **disadvantages** (Blana and Golias, 1999). First, data collected from a driving simulator generally include the effects of learning to use the simulator and may also include the effects of being directly monitored by the experimenter. Second, driving simulators, particularly high-fidelity simulators, can be very expensive to install. Simulator discomfort / sickness is another problem encountered with simulators and is particularly pronounced in older drivers (Papantoniou et al., 2013).

2.3.4 In-depth accident investigation

In-depth accident investigations are conducted by trained experts from multiple disciplines to collect as much useful information as possible in order to describe the causes of accidents and injuries. The aim of these studies is to reveal detailed and factual information from an independent perspective on what happened in an accident by describing the accident process and determine appropriate countermeasures.

In depth accident investigations **allow** the factors contributing to an accident to be identified. In addition, research into injury prevention relies on in-depth data to identify injury outcomes in different impact scenarios, including vulnerable road users, and how the interaction between different vehicle types affects injury outcome. Data from in-depth accident investigations have also been utilised in the area of development as a tool to identify ideas for new products and to evaluate the expected effectiveness of new safety systems.

On the other hand the basic **disadvantage** regarding in-depth accident investigations is the insufficient reconstruction evidence which exist in each case investigated as well as the long period which is required for the final investigation results (Hill et al., 2012).

2.3.5 Surveys on opinion and stated behaviour

In stated behaviour surveys, a reference **questionnaire** is built, based on a list of selected topics and a representative sample of population is interviewed. The survey approach can employ a range of methods to answer the research questions such as postal questionnaires, face-to-face interviews, and telephone interviews.

They produce data based on real-world observations allowing investigating **new situations**, outside the current set of experiences. Furthermore, the breadth of coverage of many people or events means that it is more likely than some other approaches to obtain data based on a representative sample, and can therefore be generalizable to a population. Moreover, surveys can produce a large amount of data in a short time for a fairly low cost, making it easier to planning and delivering end results.

On the other hand, the nature of questions is often hypothetical and the actual behaviour is not observed, while the data that are produced are likely to lack details or depth on the topic being investigated (Kelley et al., 2003).

2.3.6 Experiments overview

From the above, it can be deduced that each method for assessing driver behaviour, in the general population and in particular in the elderly, may have different **advantages and limitations** (Table 2.6). On-road studies, and their fully naturalistic versions, are considered to be more appropriate for the assessment of fitness to drive (Ball and Ackerman, 2011), however, simulators are also widely used, due to the safety and control over the experiment conditions, and despite their lower reliability. Questionnaire surveys are a very common tool for assessing various human factors of driving performance in the elderly (Vardaki and Karlaftis, 2011), yet they suffer from the known limitations of self-reported information.

Table 2.6 Comparative assessment of experiments

Experiment type	Method / tools	Advantages	Limitations
On road	Instrumented vehicle	✓ Large degree of control over the variables, ✓ examination of driver competency	– Data collection for a short period, – in response to selected interventions, – high cost
Naturalistic driving	Systems installed in participants' own vehicles	✓ Understanding normal traffic, ✓ observation of conflicts	– No experimental control of variables, – traffic incidents are very rare, – driver behaviour may not be representative,
Driving simulator experiments	Driving simulator	✓ Safe environment, ✓ greater experimental control, ✓ large range of test conditions	– learning effect, – simulator sickness, – very expensive
In-depth accident investigation	Trained experts investigate the causes of an actual accident	✓ Identification of the factors contributing to an accident, ✓ research into injury prevention	– Insufficient reconstruction evidence, – long time period
Surveys on opinion and stated behaviour	Questionnaire	✓ investigate new situations, ✓ large amount of data in a short time, ✓ low cost	– Hypothetical questions, – data lack details, – self-reported data

Consequently, the selection of method for the assessment of driver performance should be carried out in accordance to the specific objectives or **research questions** of the assessment, the time-frame and the infrastructure or resources available etc.

All types of experiments should carefully follow some basic experimental design principles, allowing for reliable analysis of the data in order to provide appropriate answers to the research questions examined. Moreover, there are various other **analysis challenges** that need to be addressed when assessing driving ability, such as the selection of appropriate and relevant driving performance measures, the application of appropriate analysis techniques, and the reliability and validity of the analysis.

2.4 Driving simulator characteristics

Driving simulators have been used to explore aspects of driving since 1960s. The main application areas of today driving simulators have been to investigate acceptability issues of innovative transport elements (e.g. mad design, in-vehicle device), to evaluate the safety concept (e.g. possible increase of accidents due to new road design, in-vehicle device), to the credibility and transferability of the simulator results to the real world as well as to the training of drivers.

Driving simulators have been used as **research** aids in a number of civil engineering, transport, psychology and ergonomics fields such as: innovative road design (e.g. testing the design of new tunnels, innovative highway design and road delineation, traffic calming); intelligent transport systems (e.g. new in-vehicle navigation systems, Head-Up-Displays, active pedals); impaired driver behaviour (driving behaviour affected by drugs, alcohol, severe brain damage, fatigue) and vehicle dynamics and layout (e.g. testing ABS, 4-wheel drive; vehicle interior design).

In this framework, in the beginning of the present chapter, **advantages** and **limitations** of driving simulators are recorded while the terms **fidelity** and **validity** are further investigated. Finally, the syndrome of **simulator sickness** is presented.

2.4.1 Advantages and limitations

A number of known advantages and disadvantages about driving simulators are the following (Regan et al., 2008).

Advantages

- Has the capability to place drivers into crash likely situations without harming them, such as when they are using drugs, fatigued, engaging in police pursuits, during extreme weather, using new technologies, among other dangerous activities.
- Many confounding variables that occur in on-road driving can be controlled when driving simulation is used (e.g., weather, traffic, lighting, frequency of vulnerable road users, wind, potholes, proportion of vehicle types, irrational or unexpected behaviour of other drivers, and so forth).
- All of the sensory details of the real world are not used by drivers anyway. Perceptual information (Gibson, 1986) for driving is knowable and can be faithfully reproduced using simulators.
- Events or scenarios can be identically repeated for each participant.
- Simulators offer cost savings through flexible configurability so that a wide range of research question can be addressed (Jamson, 2001).
- Low-cost, low-fidelity simulators in the right hands can address a wide variety of interesting research questions.
- Driving simulation is compelling and elicits emotional reactions from drivers that are similar to those of actual driving.

- Simulators are good at assessing driver performance or what a driver can do (Evans, 2004).
- A structured driver training curricula can be set up and run for new drivers and for some skills, transfers to the open road (Pollatsek et al., 2006)

<u>Limitations</u>

- Simulated crashes do not have the same consequences as a real crash and may affect subsequent behaviour. Crashes in a simulator may have an unknown psychological impact on participants.
- These confounding or interacting variables that occur in the real world also need to be understood and, since they cannot be fully recreated in simulators, are not necessarily amenable to testing (as yet). In other words, understanding driver behaviour is in the interacting details.
- The real world can never be perfectly reproduced (for now). The important combinations of real-world information and feedback that are important to driving are not completely known.
- Each exposure of trial affects responses to subsequent exposures.
- High-end simulators, such as NADs, require considerable hardware and software development to address a limited number of research questions.
- Low-cost simulators can be imprecise and inflexible and therefore do not address all needs.
- Drivers do not believe in the authenticity of the simulation at a fundamental level and responses are based on this perception.
- Simulators are not able to address questions of driver behaviour, which is what a driver does do in their own vehicle (Evans, 2004).
- The extent that the driver training transfers to on-road skills is not known nor is the relative cost-effectiveness of such programs (Jamson, 2001).

<u>2.4.2 Fidelity</u>

Fidelity refers to the level of realism inherent in the virtual world. The closer a simulator approximates real-world driving, in terms of the design and layout of the controls, the realism of the visual scene, and its physical response characteristics, the greater fidelity it is reported to have (Godley, Triggs and Fildes, 2002; Triggs, 1996). Numerous dimensions of fidelity have been proposed, many of which relate to the simulator's technical or physical characteristics, but these characteristics may not necessarily correspond to the degree to which the simulator replicates the driving experience.

Rehmann et al. (2010), proposed that there are four **interrelated dimensions** of simulator fidelity: equipment fidelity, environmental fidelity, objective fidelity, and perceptual / psychological fidelity.

- **Equipment fidelity** refers to the degree to which the simulator replicates the appearance and feel of the real – world system, in terms of the layout of the vehicle cockpit and the size, shape, color, and position of the vehicle / system controls.

- **Environmental fidelity** concerns the extent to which the simulator replicates motion and visual cues, and other sensory information from the real – world environment.
- **Objective fidelity** refers to the degree to which a simulator replicates its real world counterpart in terms of dynamic cue timing and synchronization (e.g., timing of the visual cues matching steering inputs).
- **perceptual or psychological fidelity**, is concerned with the degree to which the driver perceives the simulation to be a believable reproduction of the real driving task, and the degree to which the driver's pattern of interaction with the driving environment and system controls corresponds to real – world driving.

The level and type of fidelity required by a simulator depends on the type of **research** being conducted. It has been suggested that higher fidelity levels are required for research where the results of the simulation are used to draw conclusions about real-world driving performance, as when assessing whether interaction with an in-vehicle device distracts drivers (Triggs, 1996).

In terms of the specific aspects of simulator fidelity that are most important for distraction research, little research exists that can be used to guide this decision. However, knowledge regarding what driving performance measures are affected by distraction can provide some useful insights into what aspects of simulator fidelity might be important. For example, distraction, particularly visual distraction, has been shown to affect drivers' ability to maintain lateral position (Engstrom et al., 2005; Greenberg et al., 2003). In turn, a lack of motion and visual cues has been shown to affect the precision of lateral position control to a greater extent in simulators than actual vehicles, because the absence of visual and kinesthetic feedback leads to a decreased ability to select appropriate steering corrections (Reed and Green, 1999; Blaauwm 1982). Thus, it appears that environmental fidelity, and the precise replication of motion and visual cues in particular, is important for the accurate measurement of the effects of distraction on lateral control. Distraction has also been shown to affect drivers' visual scanning patterns and their ability to detect events occurring in the periphery (Engstrom, et al., and Ostlund, 2005; Recarte and Nunes, 2003), suggesting that a display screen with a wide field of view is important to be able to capture the effects of distraction on the detection of objects or events occurring in the driver's peripheral field of view. A simulator's fidelity can thus affect how sensitive it is to the effects of distraction.

The location of the **in-vehicle system** under evaluation, relative to the driver and the roadway, and the type and layout of its controls are also important. The location of the system in the simulated vehicle and its visual angle from the road should match precisely its placement in real vehicles because its distance from the forward view directly contributes to the degree of distraction it imposes on drivers. For example, a study on monitor location within the vehicle revealed that as the downward viewing angle of the display increased, the drivers' ability to detect that they were closing in on a lead vehicle decreased (Asoh, Kimura and Ito, 2000). In addition, the types of controls used and their layout should be consistent across the simulated and real systems. Discrepancies in the location and design of the in-vehicle system between simulated and real vehicles may lead drivers to interact with the system differently in the simulator and, thus, lead to driving performance being differentially affected across the simulated and real-world environments.

2.4.3 Validity

Simulator validity typically refers to the degree to which behaviour in a simulator corresponds to behaviour in real-world environments under the same condition (Kaptei et al., 1996; Blaauw, 1982). 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). A number of studies have examined driving simulator validity and have generally found good correlations between simulated driving performance and driving performance on real roads (Kaptei et al., 1996; Engstrom et al., 2005).

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; Harms, 1992). 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 behavioural validity for many driving performance measures, although absolute validity has rarely been demonstrated (Godley et al., 2002; Reed and Green, 1999; Blaauw, 1982; Harms, 1992; Carsten et al., 1997; McLane and Wierwille, 1975)

2.4.4 Simulator sickness

Simulator sickness has been a source of concern from the earliest days of simulator development and application (Reason, 1978; Casali and Frank, 1988). Not every individual experiences simulator sickness to the same extent, even in identical situations. Reason's (1978) neural mismatch model of sensory conflict theory states that susceptibility is a product of an individual's overall experience with motion sickness.

Like **Motion sickness**, simulator sickness has been described as a syndrome because of the breadth of its symptoms, including headache, sweating, dry mouth, drowsiness, disorientation, vertigo, nausea, dizziness, and vomiting (Ebenholtz, 1992; Kennedy et al., 1993; Cobb et al., 1999). Cobb et al. (1999) have also documented a negative effect on psychomotor control, believed to be the product of simulator sickness. Moreover, user characteristics such as age, experience, gender, illness, mental rotation ability, and postural instability play key roles in determining whether a participant will become sick.

Older adults tend to be more susceptible to simulator sickness than younger participants (Roenker et al., 2003). Additionally, simulator sickness may vary by exposure time; Cobb et al. (1999), have suggested that simulator sickness symptoms steadily increase for up to one hour during exposure to a virtual environment before returning to nominal levels 15 min later. During this adaptation period, however, some subjects may become too ill to continue and thus never reach the 1-h mark.

Finally, changes in scene content may affect the likelihood and severity of **simulator sickness** (Jones et al., 2004). While some researchers view simulator sickness as a type of motion sickness which occurs in a simulated environment, there are several reasons to treat motion sickness and simulator sickness as related but separate maladies. To begin with, motion sickness appears to occur in a larger portion of the population and tends to be more severe than simulator sickness. Additionally, a key indicator of motion sickness, drowsiness, does not necessarily indicate simulator sickness (Kennedy et al., 1993). Furthermore, eye movement disturbances are more common in simulator sickness.

2.5 Driving simulator experiments on distraction

In this section, the central part of the literature review is presented including an exhaustive review on **driving simulator studies on driver distraction**. Particularly, studies reviewed examine driver distraction through driving simulator experiments which were published in scientific journals, concern recent research and report quantitative results. Based on the results of the review, a comparative analysis assessment of the existing driving simulator experiments is carried out for the basic components of the experiment (distraction source, sample characteristics, experiments design, distraction measures etc.). Next, a critical assessment and synthesis of the results of existing studies is attempted, allowing for conclusions to be drawn with respect to the strengths and limitations of existing studies and the priority areas for improvement of future experiments.

2.5.1 Cell phone

Numerous studies have sought to examine the relative effects of hand-held and hands-free cell phones on driving performance. Research findings have typically revealed that using a hand-held phone degrades driving performance significantly and, in response, many countries have prohibited the use of hand-held cell phones while driving (Matthews et al., 2003). Based on the results of numerous studies examining hand-held 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 Headman, 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 hand-held phone (Haigney et al., 2000; Matthews et al., 2003; Redelmeier and Tibshirani, 1997; Strayer et al., 2003).

Regarding diving simulators, a range of studies have shown that the use of cell phones has adverse consequences on driver’s behaviour and the probability of being involved in an accident. Haigney et al. (2000), examined the effects on driving performance of engaging in a cell phone task using hand-held and hands-free cell phones. Thirty participants completed four simulated drives while completing a grammatical reasoning task designed to simulate a cell phone conversation. The results revealed that mean speed and the standard deviation of acceleration decreased while participants were conversing on the cell phone.

Using a driving simulator, Strayer et al., (2003) found that conversing on a hands-free cell phone while driving led to an increase in following distance from a lead vehicle and this increase was particularly pronounced under high traffic density conditions.

Rakauskas et al. (2004) used a driving simulator to determine the effect of easy and difficult cell phone conversations on driving performance, and found that cell phone use caused participants to have higher variation in accelerator pedal position, drive more slowly with more variation in speed, and report a higher level of workload regardless of conversation difficulty level.

Furthermore, Kass et al (2007) examined the impact of cell phone conversation on situation awareness and performance of novice and experienced drivers. The performance of 25 novice drivers and 26 professional drivers was measured by the number of driving infractions committed such as speeding, collisions, pedestrians struck, stop signs missed, and centerline and road edge crossings. The results indicated that novice drivers committed more driving infractions and were less situationally aware than their experienced counterparts during the cell phone conversation.

Bruyas et al. (2009) investigated whether making a conversation asynchronous (using an answer phone instead of a cell phone) reduces the negative impact of phone calls, as the communication in this occasion is under the driver’s control, allowing allows him/her to pace the interaction better. The results showed better scores for correct responses to stimuli for answer phone communications than for phone communications, although response times were higher in both communication conditions than in the driving alone condition.

Shinar et al. (2005) found that 96 minutes of dual-task simulator-based practice, distributed over 5 days, was sufficient to eliminate driving impairment from cell phone use in a group of experienced drivers. Notably, dual-task learning was primarily observed on the mean and standard deviations of lane position, steering angle, and speed. Additionally, learning was greatest when driving was coupled with a math task rather than a naturalistic conversation. From these results, Shinar et al. (2005) concluded that previous driving research had likely overestimated real-world impairment by forcing the driving pace, using unnatural conversation surrogates, and failing to repeat the driving condition.

Impairment in situation awareness regarding the surrounding traffic when using hand held cell phones while driving was found by Ma and Kaber (2005). The authors compared the impact of using a hand held cell phone while driving with the use of the adaptive cruise control system and found that the use of cell phone led to a significant reduction in the drivers' situation awareness and a significant increase in the perceived mental workload of the driver.

Beede and Kas (2006) used a driving simulator to measure the impact on driving of a conversation task on a hands free cell phone and a signal detection task while driving. Driving performance measures in terms of traffic violations, driving maintenance, attention lapses and response times were significantly impaired when participants talking on cell phones. Furthermore, conversing on the cell phone and performing the signal detection simultaneously increased the average speed, the number of attention lapses and reduced variability in speed maintenance.

McKinght and McKinght (1993) used a video driving sequence that included a total of 45 highway traffic scenes. 150 participants were tested in 5 conditions: Place a cell phone call, engage in a conversation that was either casual or intense, tune a radio or just respond to the traffic scenarios. The authors reported that participants in all conditions failed to respond to traffic events. In particular, the older group of drivers was more vulnerable to multitask demands. The younger group of participants also showed a decrease in their ability to respond to traffic scenarios that was more pronounced in the intense conversation condition.

Schlehofer et al. (2010) explored psychological predictors of cell phone use while driving for 69 college students who firstly completed a survey and predicted their driving performance both with and without a simultaneous phone conversation and finally drove on a driving simulator. Cell phone use was found to reduce their performance on the simulation task.

Reimer et al. (2010) examined the impact of distractions on young adult drivers with attention deficit hyperactivity disorder (ADHD) resulting that drivers with ADHD had more difficulty on the telephone task, yet did not show an increased decrement in driving performance greater than control participants. In contrast, participants with ADHD showed a larger decline in driving performance than controls during a secondary task in a low demand setting.

2.5.2 Conversation with passenger

Several studies attempt to compare the effect of cell phone use and passenger conversation through driving simulator experiments. In one study, eighty participants were randomly assigned to one of three conditions (Laberge et al., 2004): driving alone, driving with a passenger, and driving with a cellular phone, and results indicate that lane and speed maintenance were influenced by increased driving demands. Furthermore, response times to a pedestrian incursion increased when the driver was driving and talking compared with those detected when the driver was not talking at all.

Drews et al. (2008) examined how conversing with passengers in a vehicle differs from conversing on a cell phone while driving by comparing how well drivers were able to deal with the demands of driving when conversing on a cell phone, conversing with a passenger, and when driving without any distraction. The results show that the number of driving errors was highest in the cell phone condition; in passenger conversations more references were made to traffic, and the production rate of the driver and the complexity of speech of both interlocutors dropped in response to an increase in the demand of the traffic.

In a within-subject design (Maciej et al., 2011), the conversational patterns of 33 drivers and passengers in different in-car settings were compared to a hands-free cell phone and to a hands-free cell phone with additional visual information either about the driving situation or the driver. Participants were instructed to have a naturalistic small-talk with a friend and the results of the drivers' speaking behaviour showed a reduction of speaking while driving. Moreover, compared to a conversation partner on the cell phone, a passenger in the car varies his speaking rhythm by speaking more often but shorter.

Charlton (2009) compared the driving performance and conversational patterns of drivers speaking with in-car passengers, hands-free cell phones, and remote passengers who could see the driver's current driving situation (via a window into a driving simulator). The results indicated that driving performance suffered during cell phone and remote passenger conversations as compared with in-car passenger conversations and no-conversation controls in terms of their approach speeds, reaction times, and avoidance of road and traffic hazards.

In the Driving Simulator of the University of Calgary 40 young drivers encountered motorcycles and pedestrians while making left turns; drivers either drove alone or conversed with an attractive confederate passenger. Measures of looked-but-failed-to-see errors, hazard detection and social factors were analyzed. Higher rates of LBFTS errors and hazard detection occurred while conversing than while driving alone (White and Caird, 2010).

Furthermore, Yannis et al. (2010) investigated the effect of different types of conversation on road safety in rural roads. The results suggest that 'simple' and 'complex' conversations are associated with decreased speeds while 'complex' conversations were systematically associated with increased distance from the central axis of the lane, significantly increased reaction times at unexpected incidents and increased accident risk.

2.5.3 Music, radio

Compared to devices such as cell phones, relatively few studies have investigated the effects of interacting with in-vehicle music players and entertainment systems on driving performance (Hughesa et al., 2013; Reed-Jones et al., 2008).

In a related driving simulator experiment, 27 participants completed drives under each of three conditions: without audio materials, with audio materials from a movie, and with audio materials from radio. Performance was measured in terms of lateral control, speed control, and response to hazards and participants provided self-reports of distraction and driving impairment. Audio materials appeared to have minimal effects on driving, perhaps because listening while driving is fairly well practiced and easily modulated, and does not involve speech production (Hatfield and Chamberlain, 2008).

Chisholm et al. (2008) examined the effects of repeated iPod interactions on driver performance to determine if performance decrements decreased with practice. Measures of hazard response, vehicle control, eye movements, and secondary task performance were analyzed and resulted on increases in perception response time and more collisions while drivers were performing some difficult iPod tasks.

Moreover, in Garay-Vega et al. (2010), 17 participants between the ages of 18 and 30 years old were asked to use three different music retrieval systems while driving in order to record measures of secondary task performance, eye behaviour, vehicle control, and workload. When compared with a touch interface, the voice interfaces reduced the total time drivers spent with their eyes off the forward roadway.

Horbery et al. (2006) presented the findings of a simulator study that examined the effects of operating the vehicle entertainment system and conducting a simulated hands-free cell phone conversation upon driving performance for drivers in three age groups. The conclusions of the research are that both in-vehicle tasks impaired several aspects of driving performance, with the entertainment system distracter having the greatest negative impact on performance, and that these findings were relatively stable across different driver age groups and different environmental complexities.

Another study on the effects of using a portable music player on simulated driving performance showed that performing music search tasks while driving increased the amount of time that drivers spent with their eyes off the roadway and decreased their ability to maintain a constant lane position and time headway from a lead vehicle (Young et al., 2012).

In a similar experimental process on a driving simulator, 48 participants between 19 and 29 years old drove in a road with mountainous characteristics with and without cell phone (handheld mode) and music. Lognormal regression models were developed for driver speed and it appears that cell phone use leads to a statistically significant decrease in speed, while music tends to increase speed (Young et al., 2012).

2.5.4 In-vehicle information systems

The safety evaluation of in-vehicle information systems is less advanced, with new products being continuously marketed. It has been argued that the safety evaluation of products such as IVIS require analysis. Jamson and Merat (2005) examined the systematic relationship between primary and secondary task complexity for a specific task modality in a particular driving environment. The results show that the participants seemed incapable of fully prioritising the primary driving task over either the visual or cognitive secondary tasks as an increase in IVIS demand was associated with a reduction in driving performance: drivers showed reduced anticipation of braking requirements and shorter time-to-collision.

In order to assess whether real-time feedback on a driver's state can influence the driver's interaction with in-vehicle information systems, Domnez et al., (2006), tested 16 young and 12 middle-aged drivers' real-time feedback, through a system that alerts drivers based on their off-road eye glances, and concluded that distraction was observed as problematic for both age groups with delayed responses to a lead vehicle-braking event as indicated by delayed accelerator releases.

The findings of Reyes and Lee (2008), who examined the effects of cognitive load on driving performance for interactions with an in-vehicle information system that varied in duration from 1 to 4 minutes, suggest that two mechanisms might account for the distraction-related performance decrements in this study: competition for processing resources and interference due to activation of competing goals.

Finally, Benedetto et al. (2011), examined the effects of in-vehicle information systems usage on eye blinks in a simulated Lane Change Test and results suggest that blink duration, with respect to blink rate, is the most sensitive and reliable indicator of driver visual workload.

2.5.5 Eating, drinking, smoking, alcohol

Rakauskas et al. (2008) performed a simulator study which aimed to analyse the combined effects of distraction induced by in-vehicle tasks and alcohol on longitudinal and lateral vehicle control. Their results showed that the most pronounced effects of alcohol on lateral control were observed when drivers were distracted by a demanding in vehicle task. It is evident that it would not be feasible to investigate such an issue under on-road conditions without creating danger for participants and/or other parties involved.

In another research regarding alcohol, Harrison and Fillmore (2011) examined the interactive impairing effects of alcohol intoxication and driver distraction on simulated driving performance in 40 young adult drivers using a divided attention task as a distracting activity. As hypothesized, divided attention had no impairing effect on driving performance in sober drivers. However, under alcohol influence, divided attention exacerbated the impairing effects of alcohol on driving precision.

Young et al. (2008) investigated the impact of eating and drinking while driving. At designated points on the drive, which coincided with instructions to eat or drink, a critical incident was simulated by programming a pedestrian to walk in front of the car. The evidence suggests that the physical demands of eating and drinking while driving can increase the risk of an accident.

In the same framework, Yannis et al. (2011) analysed the effects eating and smoking on driver behaviour and on road safety in rural roads by asking participants to consume a light snack and smoke a cigarette at given points along the selected road. Results suggest that eating and smoking are associated with decreased speeds, but not with increased reaction times or accident risk.

2.5.6 Visual distraction

Visual distraction can be described as “eye-off-road” (Noy et al., 2004; Victor et al., 2005) and leads to undermining drivers’ performance. Visual distraction occurs when drivers look away from the roadway, while cognitive distraction affects driving by disrupting the allocation of visual attention to the driving scene and the processing of attended information.

Liang and Lee (2010), Kaber et al., (2012) and Muhrer and Vollrath (2011), compared driving without distraction to visual distraction, cognitive distraction, and combined visual and cognitive distraction and the results show that the visual and combined distraction both impaired vehicle control and hazard detection and resulted in frequent, long off-road glances.

Regarding visual distraction, in a recent research (Metz et al., 2011), 40 participants were asked either to solve an externally paced, highly demanding visual task or a self-paced menu system task. Results indicate that collisions go together with an inadequate distribution of attention during distraction. The results are interpreted regarding the attentional processes involved in driving with visual secondary tasks.

Within this framework, Fofanova and Vollrath (2011) examined the effect of age on driving performance as well as the compensation strategies of older drivers under visual distraction. The results show that older participants’ overall driving performance (mean deviation from an ideal path) was worse in all conditions as compared to the younger ones and that with regard to lane change reaction time both age groups were influenced by visual distraction in a comparable manner.

Furthermore, Terry et al., (2008) assessed the ability of drivers to detect the deceleration of a preceding vehicle in a simulated vehicle-following task while the size of the preceding vehicles (car, van, or truck) and following speeds (50, 70, or 100 km/h) were systematically varied. Interestingly, increases in vehicle size had the effect of decreasing drivers' braking latencies and drivers engaged in the secondary task were significantly closer to the lead vehicle when they began braking, regardless of the size of the leading vehicle.

2.5.7 Advertising signs

According to the international literature, external driver distraction sources are a minor proportion of road accident causes. However, the particular case of advertising signs is often considered and several studies examine the effect of roadside advertising on driver attention, behaviour and safety. In most countries, specific rules exist as per the size, location and type of roadside advertisements.

Edquist et al. (2011) examined the effects of billboards on drivers, including older and inexperienced drivers, and suggested that billboards changed drivers' patterns of visual attention, increased the amount of time needed for drivers to respond to road signs, and increased the number of errors in this driving task.

Within the same framework, twelve volunteers participated in driving simulator drive on two identical paths, one with roadside advertising signs and one without (Bendak and Al-Saleh, 2010). Results revealed that two driving performance indicators, drifting from lane and recklessly crossing dangerous intersections, were significantly worse in the path with advertising signs as compared with performance on the other path. The other three performance indicators (number of tailgating times, over-speeding and turning or changing lanes without signaling) were also worse in the presence of advertising signs but the difference was not statistically significant.

Another simulator study, Young et al. (2009) quantified the effects of billboards on driver attention, mental workload and performance in urban, motorway and rural environments. The results demonstrate that roadside advertising has clear adverse effects on lateral control and driver attention, in terms of mental workload.

2.6 Assessment of driving simulator studies on driver distraction

The literature review presented in the previous section reveals that driving simulator experiments on driver distraction have provided **valuable insight** into some causes and impacts of driver distraction, by various distraction sources, in-vehicle or external. For example, the available results allow for the quantification of the effects of various distractors on driver behaviour and safety in different conditions, as well as the comparative assessment of different types of distraction in the same conditions. Most studies have clear objectives and address specific research questions concerning individual aspects of distracted driving.

As a consequence, the experiments **vary considerably** in terms of sample characteristics, design and analysis methods. There is little uniformity in the way the experiments are conceived, conducted and exploited; while this does not constitute a limitation by itself, it may complicate the synthesis of results and the drawing of conclusions. For that purpose, the existing studies were classified with respect to a number of key components of the experiments and methodologies, allowing their comparative assessment.

To begin with, the **distraction sources** examined and the sample characteristics are summarized in the first part of Table 2.7. In almost all studies examined, distraction was induced in some way by the experimenter, often by letting the participant perform a secondary task. These tasks can correspond more or less to what drivers might do in real traffic. The tasks may be visual, auditory, motor or combined, they may be simple or complicated, and they may require immediate attention or leave the driver some leeway in deciding when to attend to the task. A large number of simulator studies concern cell phone distraction while driving, and its comparison with other distractions. Conversation with passengers and manipulation of in-vehicle information systems are often examined. For the other distraction sources, only a small number of simulator studies were available.

As regards the **sample characteristics**, it is observed that in the majority of studies 30-40 participants implemented the driving scenarios (average number is 38). Given that most studies examine additional parameters to distraction, such as driver age or experience road types etc., these sample sizes may or may not have sufficient power to reach conclusions, but sample power is not reported in the majority of studies.

In several cases, equal numbers of male and female participants were examined. In the vast majority of studies the focus is on young (18-25 years old) or middle aged (26-55 years old) participants, while only a small proportion (17%) of the researches examine older drivers (defined here as those aged >55 years old). This is possibly due to practical recruitment issues; for instance, several studies have easily recruited university students, who are directly accessible. Such limitations in sample **representativity** are acknowledged by the authors, and although the experiment design and analysis methods may be appropriate, it is not possible to generalize the results over the entire driver population.

Concerning the **design and implementation** of the experiments, the results of the comparative assessment of existing experiments are presented in the second part of Table 2.7. These vary considerably in terms of design principles and parameters examined, due to the different scopes, research questions, simulator types and resources available. Nevertheless, this lack of uniformity raises difficulties when attempting to make a synthesis of the results.

Participants in almost all driving simulator experiments implemented a **practice scenario**, in order to get familiar with the simulator. The duration of this scenario varies enormously but in most cases exceeds 5 minutes. However, it is not reported whether specific performance measures were used to assess the driver’s familiarization with the simulator before proceeding to the main experiment (Sahami and Sayed, 2010). Ronen and Yair (2013) aimed to explore whether roads of different complexity and demand (curved, urban and straight) require different adaptation time and to examine the relationship between participants’ subjective sensation of acclimation and objective driving performance measures. Results indicate that while sensation of adaptation can give a relatively good indication of adaptation for a variety of performance measures, it would be preferable if it is used in addition to multiple performance measures for an accurate assessment of the adaptation period necessary for each road type.

The total number of **experimental trials** that drivers are asked to complete vary from 1 to 16 while in the vast majority of studies the number of trials varies between 2 and 6. In the majority of studies, 2 trials are typically the case, one with and one without distraction, while in 10% of studies only 1 trial was scheduled, during which a distracted driving task took place at some point. The length / duration of each trial varied enormously, and not proportionally to the sample size, the number of parameters or distraction sources examined, or the total number of trials to be performed. As a consequence, there are experiments with few long trials, others with few short trials, others with many short trials, and a few with many long trials. The number and duration of trials is directly related to the driver workload, and it is possible that the effect of a distractor is more or less pronounced during a long drive than during a short one, and possible confounders include fatigue, simulator sickness etc. Moreover, driver workload may be affected in a different way when there are many shorter trials, and in this case possible confounders include learning effects, fatigue, loss in simulator fidelity etc. Consequently, it can be difficult to generalize the results for a given distractor from existing studies with such differences in experiment design. It is important to note that despite these differences, the results of the studies are generally consistent as regards the sign of the effects, but less consistent as regards the magnitude of the effect.

In this framework, another possible criticism of reviewed researches is the handling of **learning effect**. Learning effect can arise from repeated exposure to the same or similar driving simulator scenarios or tasks. In order to reduce the effect of this potential confound in simulation studies, repeated testing scenarios counterbalancing or randomly presenting multiple scenarios or tasks can be used. However, in 30% of studies examined no counterbalancing in the different trials was reported, indicating that learning effects may have not been treated effectively.

As regards the simulated **road environment**, most driving scenarios concern rural road environment, while less than 30% concern motorways. The relatively smaller proportions of urban environments may be partly attributed to the researcher's effort to minimize simulator sickness, which is known to be more intense in more complex settings. However, in-vehicle distraction may be equally or more important in urban areas, where the driver is by default exposed to several other 'distractors' (e.g. traffic signs, other vehicles or pedestrians, advertising, architecture and commercial activities etc.).

Table 2.7 Overview of driving simulator experiments

			Distraction Source							Sample Characteristics							Experiment design																	Driving-related Outcomes								Statistical Analyses			
																	Driving Simulator		Practice trial			Trial duration		Total Duration			Road environment				Traffic conditions														
	Authors	year	cell phone	conversation	visual	music	IVIS	advertisign signs	eat, drink, alcohol	sample size	% male	25-	26-55	55+	benefits	questionnaire	fixed based	motion based	<5min	>5min	Number of trials	km	min	km	min	**Counterbalancing**	lanes	urban	rural	motorway	Ambient traffic	lead vehicle only	opposite traffic only	speed	lane position	reaction time	perception / situation	headway	accident probability	eye glance	acceleration / deceleration	Descriptive statistics	One way ANOVA	Two way ANOVA	Repeated measures ANOVA
1	Laberge et.al	2004	•	•						80	50%	•				•		•			2	4,0		8,0				•			•			•	•								•		
2	Drews et.al	2008	•	•						96	25%	•	•		•		•			•	3		5,0		15,0	•	2		•		•			•	•								•		
3	Charlton	2009	•	•						112	50%	•	•	•	•	•	•				1	25,3	24,0	25,3	24,0	•	2			•	•			•				•	•					•	
4	Yannis et.al	2011	•	•					•	42	48%	•			•	•	•		•		3	4,0		12,0					•		•			•	•	•			•						•
5	Hunton andRose	2005	•	•						111	25%				•				•		1		30,0				3	•											•				•		
6	Horbery et al	2006	•			•				31	-		•	•		•		•	•		6	6,0		36,0		•	1		•					•										•	
7	Reed-Jones et	2008	•			•				32	44%	•					•				7		10,0		70,0	•							•	•					•				•		
8	Yannis et.al	2011	•			•				48	50%	•				•	•		•		1	6,5		6,5							•			•	•	•			•				•		
9	Rakauskas et al	2004	•							24	50%					•		•			6		1,7		10,0	•	2		•		•			•	•				•					•	
10	Kass et al	2007	•							49	49%	•	•	•			•		•		1		11,5		11,5																		•		
11	Bruyas et al	2009	•							30	50%	•	•		•	•	•			•	4		11,0		44,0		1		•				•												•
12	Reimer et al	2010	•							60	60%	•			•	•	•			•	1	56,0		56,0				•		•	•			•			•				•		•		
13	Schlehofer et al	2010	•							69	36%	•			•	•	•		•		2		7,0		14,0	•			•															•	
14	Ma and Kaber	2005	•				•			18	50%	•				•	•			•	4				100,0	•				•		•		•	•			•					•		
15	Beeder and Kas	2006	•				•			36	-	•	•			•	•			•	4				60,0	•		•			•			•	•	•								•	
16	McKnight and Mc	1993	•				•			150	50%	•	•	•			•				5									•							•						•		•
17	White et al	2010		•						40	50%	•				•		•			2					•	2	•	•										•				•		•
18	Maciej et al	2011		•						33	52%	•			•	•					11		18,2		200,0	•																	•		•
19	Noy et al	2004			•					24	63%	•	•		•	•	•				5		12,8		64,0		2		•		•			•									•		•
20	Donmez et al	2006			•					28	-		•	•	•	•	•				16					•	2		•														•		
21	Donmez et al	2008			•					48	52%	•			•	•	•			•	4		30,0		120,0		2		•		•			•	•			•	•	•			•		•
22	Liang et al	2010			•					16	50%	•	•		•		•			•	8		8,0		64,0	•	2	•	•		•				•		•						•		•
23	Fofanova et al	2011			•					20	80%			•						•	4					•	3							•									•	•	
24	Muhrer et al	2011			•					28	50%	•	•		•	•	•			•	2		33,0		66,0	•					•			•				•						•	
25	Metz et al	2011			•					40	55%		•							•	8		10,6		85,0				•		•									•					
26	Kaber et al	2012			•					20	50%	•			•	•	•			•	8		8,0		64,0	•	2					•											•		
27	Zhang et al	2012			•					24	50%	•	•	•		•	•				6		25,0		150,0	•			•		•			•						•					•
28	Hatfield et al	2008				•	•			27	48%		•		•	•	•		•		3	6,5		19,5		•	2	•	•		•			•	•		•		•						•
29	Chisholm et al	2008				•				19	53%	•			•		•				6		6,0		36,0		3			•	•				•		•			•			•		
30	Garay-Vega et al	2010				•				17	71%	•	•		•	•	•				8		4,0		32,0			•	•		•									•					•
31	Young et al	2012				•				37	46%	•	•		•	•	•			•	5		18,0		90,0	•	2	•						•	•								•		
32	Hughes et al	2012				•				21	5%	•	•			•	•		•		6	1,1		6,6		•	2				•			•	•										•
33	Jamson et al	2005					•			48	-		•				•			•	3	10,0	6,7	30,0	20,0	•	1				•														•
34	Donmez et al	2007					•			29	48%	•			•	•	•				4		3,8		15,0	•	2		•			•		•							•		•		
35	Reyes et al	2008					•			12	50%		•		•		•			•	6		7,5		45,0	•					•					•					•		•		•
36	Jamson et al	2010					•			18	50%		•		•		•				2					•	1		•		•			•	•								•		•
37	Benedetto et al	2011					•			15	80%					•			•		6	3,5		21,0		•										•							•		•
38	Birrell et al	2011					•			25	56%		•			•	•		•		6					•	2				•			•				•			•		•		•
39	Terry et al	2008						•		78	55%	•	•	•		•	•			•	2	7,5		15,0		•			•							•		•						•	
40	Young et al	2009						•		48	60%		•		•		•		•		6		5,0		30,0	•		•	•	•					•					•			•		
41	Bendak et al	2010						•		12	100%	•	•			•	•			•	2	9,3		18,6		•	3				•			•						•		•	•		
42	Edquist et al	2011						•		48	63%	•	•	•	•	•		•			2	9,0		18,0		•	3	•	•			•			•					•			•		
43	Rakauskas et al	2008							•	45	100%	•			•			•			2		2,0		4,0	•	4			•		•											•		
44	Young et al	2008							•	26	62%	•	•	•	•						2	9,8		19,5		•	1	•			•			•	•									•	
45	Harrison et al	2011							•	40	50%	•	•		•	•					1	9,5		9,5				•						•					•				•		

Surprisingly, the effect of **ambient traffic** is not examined in all distracted driving experiments, as 30% of experiments are carried out at the absence of other vehicles on the simulated road network and 17% are carried out at the presence of a single leading vehicle. This is possibly due to the fact that the simulation of ambient traffic is a complex and demanding task, which, if not carried out explicitly, may be introducing a possible confounder in the experiment. The lack of ambient traffic, while on the one hand allows to control for a possible confounder, on the other hand may result in a loss in realism. The simulation of a single lead vehicle is a common way of examining vehicle interaction at distracted driving, but may still be considered as a simplification of actual traffic conditions. Again, when attempting to comparatively assess different studies on a given source of distraction, it is important to consider the type and extent of ambient traffic simulation in these studies.

A final remark concerns the **quantitative measures** used to express driver distraction. In most cases, driver distraction is measured in terms of its impact to driver attention, driver behaviour and driver accident risk. It is noted that the specific measures used vary significantly, and the driving-related outcomes can be ranked as follows, in terms of frequency: speed, lane position (position of vehicles, crossing the center of median lane, steering angle), accident probability, number of eye glances, headway, reaction time, overtaking, acceleration and deceleration, and hazard/risk perception and situation awareness (based on probing participants). Certainly, the effects of distraction need to be studied on a variety of different driving performance measures to better understand which measures of driving might be most vulnerable to the disruptive effects of distraction.

However, the **diversity in the measure**s used, in combination with the **diversity in the design** of the experiments (i.e. road and traffic factors examined, number and duration of trials) often complicates the synthesis of the results, especially for the less commonly examined distractors. For example, reaction times at unexpected incidents have been found to be very sensitive to several distraction sources and can be directly interpreted in terms of safety; however, there is little or no information on the effects on reaction times for some key distractors such as the IVIS. On the other hand, mean speed and acceleration are examined by the majority of researchers in terms of distracted driving and the related effects are very well documented, therefore it may be suggested to shift the research focus on other measures. As another example, time or space headways may be less appropriate measures as they heavily depend on the type of simulated ambient traffic (i.e. whether the lead vehicle behaviour is explicitly simulated or is left random).

Another related remark can be made: studies focusing on visual distraction are – naturally – more focused on driver attention measures (e.g. eye glances etc.), while studies examining motor and cognitive distractors such as cell phones are more directly concerned about driving performance measures (e.g. Speeding, lateral control etc.). This diversity, despite its advantages, limits the potential for using the existing studies in order to answer more global questions related to driver distraction. Such questions are: what type of distraction is more detrimental for driver safety? What distracted driving behaviour is more risky?

Furthermore, concerning statistical analyses methods, in the majority of studies different types of Anova are implemented. More specifically, in 55% of the examined studies the main statistical analysis is repeated measures Anova. This is probably explained by the fact that in most driving simulator experiment participants are to drive more than one times, apart from the practice drive. This means that repeated measure analysis is expected to have been carried out in most researches. Consequently, 5% of the examined studies perform only descriptive statistics tests aiming to gain general information regarding different performance measures, while in only a few researches linear regression models are implemented.

On the other hand, a very interesting finding from this literature review is that **none of the examined researches used latent variables 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.

2.7 Synthesis of review findings

The objective of the present PhD thesis is the in-depth analysis of the effect of driver distraction on driver behaviour and road safety. On that purpose, a thorough **literature review was carried out** and presented in this chapter examining in a comprehensive way driving behaviour, driver distraction, driver distraction assessment, driving simulator characteristics as well as driving simulator studies on driver distraction. From all these complementary reviews several specific conclusions are extracted and presented here-in.

- While **human factors** are the basic cause of road accidents, driver distraction is one of the most usual contributory factor.

- The quantification of the **causes and impacts of driver distraction** on driver behaviour and safety has been attempted in numerous studies. However, the results, although consistent overall, lie on a range of values, mainly due to the different definitions of driver distraction and the different distraction sources taken into account in each study. As a consequence, the level at which driver distraction affects both driver behaviour and road safety has not been investigated sufficiently in the international literature.

- Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). **Driver distraction factors that occur inside the vehicle seem to have greater effect on driver behaviour and safety**

- Driver distraction may have an impact to **driver attention** (i.e. hands-off the wheel, eyes-off the road), **driver behaviour** (i.e. vehicle speed, headway, vehicle lateral position, driver reaction time) and **driver accident risk**.

- Drivers self-regulate their driving to compensate for any decrease in attention to the driving task. **Compensatory or adaptive behaviour** can occur at a number of levels ranging from the strategic to the operational level.

- Several methods exist for assessing driving behaviour such as naturalistic driving experiments, driving simulator experiments, on road experiments, in-depth accident investigations and surveys on opinion and stated behaviour. **The selection of method** for the assessment of driver performance should be carried out in accordance to the specific objectives or research questions of the assessment, the time-frame and the infrastructure or resources available etc.

Furthermore, the literature review regarding driving simulator studies on driver distraction reveals that although simulator studies on driver distraction provide **useful insights** into how driver, vehicle, and roadway characteristics influence distracted driving behaviour and safety, the design and implementation of such experiments is still inconsistent and often does not conform to experimental design principles. The following conclusions constitute the experimental research questions of the present PhD thesis and are taken into account in the design of the present simulator experiment.

- Overall, the findings of this review highlight the need for **larger scale** simulator studies on driver distraction (larger and more representative samples), more standardised experiment designs and more uniform measures of driver distraction. Dealing with these challenges is a critical component of the design of the distracted driving simulator experiment carried out within the present research.

- More specifically, **key characteristics** of the sample being investigated need to be examined with caution, including age distribution (mean and range), gender, mental status, cognitive functions, visual function etc. Participants' recruitment process is also likely to be a critical component of the sampling scheme.

On the basis of the **comparative assessment** of these studies, it is found that at the majority of studies, the most common distraction sources examined are cell phone use, conversation with passengers and visual distraction, as well as their comparisons. Most experiments are based on very small samples, limited to rural road environment, with non-explicit (if at all) simulation of ambient traffic. No pattern could be identified as regards the selection of number and duration of trials. Moreover, it is a matter of some concern that the size of the experiment is not adequately adjusted to the sample size in several studies.

The importance of the questions related to driver distraction becomes more pronounced when considering the existence of various endogenous factors that may affect driver attention or distraction. These factors encompass demographic, personality and behavioural characteristics.

The identification of specific **distraction mechanisms** for each cause of exogenous distraction, in combination with potential normal or pathological endogenous factors, is expected to provide an improved understanding and new insights regarding the causes of driver distraction. Such results are expected not only to complement existing knowledge on driver distraction, but also to improve the existing methods of analysis and the tools used in the traffic engineering, medical and neuropsychological research on the topic.

The literature review presented in this report suggests that the **design and implementation of such an experiment** can be a demanding task. Existing experiments' design is still inconsistent and often does not conform to experimental design principles, making it difficult to compare across studies and identify good practices. Moreover, the importance of complying with basic experiment design features, such as: sample power, type of design (between- or within-subject, or mixed, full or fractional factorial design), extent of counterbalancing etc., has been confirmed by the results of the review.

3. Methodological approach

This chapter presents the methodological approach of the present PhD thesis. To begin with, a brand new **methodological approach** is a central component of this research. For this purpose, an extended literature review (presented in chapter 2) took place in order to investigate the key driving performance measures as well as the statistical analyses implemented in the scientific field of driver distraction. Based on this literature review, the critical driving performance measures are selected and an innovative statistical methodology is developed for the investigation of the effect of distraction on driving performance and accident risk.

In the beginning of this chapter, **driving performance measures** examined in driving simulator experiments are presented and analysed including lateral control, longitudinal control, reaction time, gap acceptance, eye movement and workload measures. Furthermore, a list of the most common driving simulator dependent variables is cited.

Next, based on the literature review presented in chapter 2 regarding statistical methods implemented in driver distraction experiments, an innovative **statistical methodology analysis** is developed which is consisted of the following phases:

The first phase concerns the development of **regression models** (general linear models, (general linear mixed models) regarding key performance parameters of the database. Such models are often used in driver distraction analysis in order to estimate the effect of distraction sources on specific driving performance parameters and indirectly on driving behaviour and road safety.

The second phase of the analysis methodology, is the central component of the PhD thesis as for the first time **latent analysis** is implemented on driver distraction research. The main goal of this attempt is to estimate directly the effect of driver, road and traffic environment characteristics both on driving performance, driver errors and accident probability. In order to achieve this target, latent models analysis is implemented including factor analysis and

Structural Equation Models (SEM). Within this framework, the **theoretical background** of all steps of the selected statistical analyses are presented in this chapter.

Finally, a **synopsis** of the overall methodology is presented.

3.1 Driving performance measures

As there are a lot of different **methods and measures** that exist for evaluating driving performance, the selection of the specific measures for driver distraction research, as in other areas of research, should be guided by a number of general rules related to the nature of the task examined as well as the specific research questions.

This chapter reviews a range of **assessment measures** that have been used in order to assess the impact of distraction on driving performance including lateral control, longitudinal control, reaction time, gap acceptance, eye movement and workload measures. Finally, a list of the most common driving simulator dependent variables is cited and some general remarks are provided.

3.1.1 Longitudinal control measures

A range of **Longitudinal Control Measures** can be examined in driver distraction research. Two of the most common are speed and headway which are further analysed below.

3.1.1.1 Speed

The relationship between **speed** and accidents is widely recognized in the road safety community and as such, speed is a commonly used dependent variable in transportation human factors research including driver distraction research. A number of speed related measures can be calculated including, average speed, speed variability, 85^{th} percentile speed, maximum speed (Hogema and van der Horst, 1994; Manser and Hancock, 2007)

On distracted driving, the most common pattern is to adopt slower speed to increase available response time (Chu, 1994). Drivers use this strategy in order to exert some control over their circumstances and compensate for increased reaction time. It has also been shown that drivers display greater speed variability and throttle control while talking to the cell phone (Haigney et al., 2000; Rakauskas et al., 2004; Yannis et al., 2010; Beede and Kas, 2006).

3.1.1.2 Headway

Headway or vehicle following measures are also commonly employed in driver distraction research. Several measures have been commonly used including mean headway (distance or time based), minimum headway and standard deviation of headway. Headway is an indication of the safety margin that drivers are willing to accept, and thus, short headways are often interpreted as being indicative of degraded driving performance and a measure of high secondary task load (Regan et al., 2008).

A number of studies has shown, however, that drivers tend to adopt longer headways when interacting with secondary tasks, particular visual tasks (Greenberg et al., 2003; Östlund et al., 2004). For example, drivers engaging in a cognitively demanding cell phone conversation often maintain longer headway distance in a car-following situation as compared to when driving without a distraction task (Ranney et al., 2005; Strayer et al., 2003; Strayer and Drews, 2004). Furthermore, the distribution of headways for a given driver may reflect following preferences and the need to respond to surrounding traffic. Drivers who maintain a greater headway may have others pull into their headway gap. Certain drivers attempt to block others from pulling into a gap ahead, though at this point, there has never been a scenario designed to assess this behaviour (Dudek et al., 2006).

3.1.2 Lateral control measures

Lateral Control Measures assess how well drivers maintain vehicle position within a lane. These include lateral position, standard deviation of lateral position and steering wheel metrics. Lateral control measures can be sensitive to eyes off the road from distractions, perceptual-motor declines, and some cognitive declines. However, lateral control measures are also affected by the handling characteristics of the driving simulator, and the simulator vehicle may differ markedly from the one that the participant normally drives. More specifically, drivers may have more problems adapting to these differences in handling, and this may be especially problematic when frequent right and left turns are required. Consequently, it is vital that participants are given adequate practice so that they can get used to how the simulator vehicle handles (Regan et al., 2008).

3.1.2.1 Lateral position

Lateral position or Lane keeping refers to the position of the vehicle on the road in the relation to the center of the lane in which the vehicle is travelling. Decrements in lateral position control are used as a measure of secondary task load when evaluating the effect on in-vehicle distractions sources on driving performance (Greenberg et al., 2003; Green et al., 2004; Van Winsum et al., 2000). An interesting finding with respect to lateral position is that moderate levels of cognitive load have been shown to lead to more precise lateral position, by reducing lane keeping variation (Engrom et al., 2005).

In two meta-analyses of the effect of cell phone usage on driver performance, Horrey & Wickens (2006) and Caird et al. (2008) found only a modest effect of distraction on lateral control, suggesting that cell phone conversation has minimal effect on lane keeping. A possible reason for these mixed findings is that the effects of distraction on lane keeping performance depend on the modality and demand of the secondary tasks. Visual, manual and cognitive distraction apparently have different effects on lane keeping performance (Liang & Lee, 2010)

3.1.2.2 Steering wheel control

Measures of **steering wheel control** have been used extensively in many forms of driving research. These include standard deviation of steering wheel angle, steering wheel reversal rate, steering wheel action rate, steering entropy. In driver distraction and workload research, steering wheel movements are considered to be an indicator of a secondary task load. When driving without any distraction source, drivers make a number of small corrective steering wheel movements to maintain lateral position while in distracted driving drivers often make a number of large and abrupt steering wheel movements to correct driving errors (Regan et al., 2008; Brooks et al., 2005; McGehee et al., 2004)).

In addition, cognitive distraction was found to increase steering wheel manipulation (Ranney et al., 2005; Seppelt and Wickens, 2003). In an on-road driving study, an auditory continuous memory task significantly increased the steering wheel reversal rate (with one degree gap threshold), compared to drive-only conditions (Engström et al., 2005).

3.1.3 Reaction time measures

Reaction time measures is an increasingly popular set of variables primary because of the relationship with accident risk. A range of reaction time measures can be examined including number of missed events, number of incorrect responses, reaction time and reaction distance. Drivers' ability to detect and react (most often at unexpected incidents) has been shown to be impaired by in vehicle distraction sources, particularly with complex devices. In this framework, a number of studies has shown that handheld or hands free phone increases driver's reaction time by up to 30% (Yannis et al., 2010; Horrey and Wickens, 2006; Ishigami and Klein, 2009; Hancock et al., 2003).

Furthermore, several studies have examined the influence of driver demographics like age and gender on reaction times of distracted conditions. Similar impairment of reaction times was reported by Caird et al. (2008), where there action times were 0.46 s and 0.19 s slower, respectively, for distracted older and young drivers. An experiment on an advanced driving simulator by Nilsson and Alm (1991) showed that elderly drivers' reaction times to an unexpected event were approximately 0.40 s greater than that for young drivers when distracted by a cell phone conversation.

3.1.4 Gap acceptance measures

Despite its importance, not many studies have been conducted on modeling passing **gap acceptance** behaviour. Early studies in this area discussed drivers' perception of the required gaps for passing (Jones and Heimstra, 1966; Farber and Silver, 1967; Gordon and Mast, 1968) while other studies focused on examining the major components of the passing process and factors which affect this process, such as the required sight distances (Polus et al., 2000; Glenon, 1998; Brown and Hammer, 2000; AASHTO, 2004).

Negotiating gaps in traffic is a complex task requiring considerable visual guidance and attention. Gap acceptance measures that have been used in distraction research include number of collisions initiated and gaps accepted. Research shows that when using in vehicle distraction sources such as cell phones, drivers tend to accept shorter gaps in traffic when turning compared to undistracted driving (Farah et al., 2007).

3.1.5 Eye movement measures

It has become increasingly common to use **eye movement** systems in driving simulator studies although there is a number of limitations that have to be carefully considered. Furthermore, fixations, saccades, and smooth pursuits represent three types of eye movements that can be used to help identify cognitive distraction. Fixations occur when an observer's eyes are nearly stationary. The fixation position and duration may relate to attention orientation and the amount of information perceived from the fixated location, respectively (Hayhoe, 2004). Saccades are very fast movements that occur when the eyes move from one point of fixation to another. Smooth pursuits occur when the observer tracks a moving object, such as a passing vehicle. They serve to stabilize an object on the retina so that visual information can be perceived while the object is moving relative to the observer. In the context of driving, smooth pursuits have a particularly important function; they capture information from the dynamic driving scene. Both fixations and smooth pursuit movements may reflect the how cognitive distraction interferes with how drivers acquire visual information (Liang et al., 2007).

In this framework, a large number of eye movement measures can be collected including: Glance, Eyes-off-road-time, Fixation and Percent Dwell Time (PDT).

3.1.6 Workload measures

There is still no universally accepted definition for **mental workload**. One proposed definition is: "Mental workload is a hypothetical construct that describes the extent to which the cognitive resources required to perform a task have been actively engaged by the operator" (Gopher, 1986). Another definition of mental workload proposed by Verwey (2000) is that "mental workload is related to the amount of attention required for making decisions." Just defining the concept of workload is not enough; there must also be a way to measure it. Since there is not even an accepted definition of workload, it is not surprising that there is not a single way to measure it either. There are three main classifications for measurement of workload: physiological, subjective, and performance-based measures (Miller, 2001).

3.1.6.1 Subjective measurement

Subjective measurement of levels of workload is based on the use of rankings or scales to measure the amount of workload a person is feeling. Subjective workload measures are devoted primarily to the intermittent question-answer type response to varying levels of workload. The two main types of scales used to measure subjective workload are unidimensional and multidimensional scales (Miller, 2001).

Unidimensional rating scales are considered the simplest to use because there are no complicated analysis techniques. The unidimensional scale has only one dimension. Generally, the unidimensional scale is more sensitive than the multidimensional scale (De Waard, 1996). The multidimensional workload scale is considered to be a more complex and more time consuming form of measurement, and has from three to six dimensions. The multidimensional scale is generally more diagnostic (De Waard, 1996).

Several simple subjective mental workload scales have been developed to measure an individuals' perceived workload. Some of the main scales used in the driving domain include NASA-task Load Index (TLX), Rating Scale Mental Effort (RSME), Situation Awareness Global Assessment Technique, Driving Activity Load Index (DALI) (Miller, 2001).

3.1.6.2 Physiological measurement

Physiological measurement of workload is a factually based concept that relies on evidence that increased mental demands lead to increased physical response from the body (Moray, 1979). Physiological workload measures are devoted primarily to continuous measurement of the physical responses of the body.

Most research focuses on five physiological areas to measure workload: cardiac activity, respiratory activity, eye activity, speech measures, and brain activity. Cardiac activity is measured through heart rate, heart rate variability, and blood pressure. Respiratory activity measures the amount of air a person is breathing in and the number of breaths in a given amount of time. Eye measures mainly include horizontal eye movements, eye blink rate, and interval of closure, but there are several other less accepted measures. Speech measures take pitch, rate, loudness, jitter, and shimmer into account when determining workload. To measure brain activity, either the electroencephalograph (EEG) or electro-oculogram (EOG) are usually used (Miller, 2001).

3.1.6.3 Performance measurement

"Performance may be roughly defined as the effectiveness in accomplishing a particular task" (Paas & Vanmerrienboer, 1993). The two main ways to measure workload by means of performance are **primary** and **secondary measures**. The basis for using primary and secondary tasks to measure workload is based on the assumption that people have limited resources (Yeh & Wickens, 1988).

Derrick (1988) explains how the “tasks that demand the same resource structure will reveal performance decrements when time-shared and further decrements when the difficulty of one or both is manipulated.” This means that workload can be estimated by measuring the decrease in performance by either the primary or secondary tasks. The primary task measure is a more direct way to measure workload than the secondary task measure, but both are used and at least moderately accepted.

3.1.7 Summary of driving performance measures

Driver distraction is a multidimensional phenomenon which means that no single driving performance measure can capture all effects of distraction. The large number of measures, presented in table 3.1, indicates that the decision regarding which measure or set of measures is used should be guided by the specific research question (Regan et al., 2008).

However, recent research offers **valuable insights** into what measures are most appropriate for particular evaluations. More specifically, visual distraction has a greater effect on lateral control measures, whereas cognitive distraction affects more visual scanning behaviour. Furthermore, the type of distraction source being assessed should influence measurement selection.

Table 3.1 Common driving simulation dependent variables (Regan et al., 2008)

Variable Classification	**Variable**
Lateral Control	Lateral Position
	Lateral Position variability (SDLP)
	Lane exceedances (LANEX)
	Time to Lane Crossing (TLC)
	Reversal Rate (RR)
	Standard deviation of steering wheel angle
	Steering wheel reversal rate
Longitudinal Control	Speed
	Speed Variability
	Time of Distance Headway
Reaction time	Perception Response Time (PRT)
	Brake Response Time (BRT)
	Time to Collision (TTC)
Gap acceptance	Number of collisions
	Gaps accepted
Eye Movements	Glance
	Eyes-off-road-time
	Fixation
	Percent Dwell Time (PDT)
Workload, Subjective	NASA-task Load Index (TLX)
	Rating Scale Mental Effort (RSME)
	Situation Awareness Global Assessment Technique
	Driving Activity Load Index (DALI)
Workload, Physiological	Heart Rate (HR)
	HR Variability
	Respiration
	Electroencephalography (EEG)
	Skin Conductance
Crash	Crash
Other Measures	Entropy
	Safety Margins
	Navigation
	Other higher-order or aggregate measures

3.2 Statistical analysis methodology

To achieve the objectives set out in this PhD thesis, an innovative **analysis methodology** has been developed exploiting a set of existing and advanced statistical mathematical models. For the development of this innovative analysis methodology all statistical modelling limitations and needs were taken into account, as derived from the extended literature review presented in the preview chapter.

More specifically, in 55% of the examined studies the main statistical analysis is repeated measures Anova. This is probably explained by the fact that in most driving simulator experiment participants are to drive more than one times, apart from the practice drive. Consequently, 5% of the examined studies perform only descriptive statistics tests aiming to gain general information regarding different performance measures, while in only a few researches linear regression models are implemented.

On the other hand, a very interesting finding from this literature review is that **none of the examined researches used latent variables 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.

The innovative analysis methodology developed consists of four steps as follows.

In the first step, **descriptive statistics** are used to describe the basic features of the data as they provide simple summaries about the sample and the measures. Together with simple graphics analysis, they form the basis of virtually quantitative analysis of data.

The second step concerns the development of **regression models** (general linear models, general linear mixed models) with regard to key performance parameters. Such models are often used in driver distraction analysis in order to estimate the effect of distraction sources on specific driving performance measures and indirectly on driving behaviour and road safety.

In the next step, **factor analysis** is implemented regarding driving performance and driver errors in order to investigate which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the data. This type of analysis is designed 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.

In the fourth step, the central part of the statistical analysis of the present PhD thesis is taking place including the implementation of **structural equation models** for the first time in the scientific field of driver distraction. Within the framework of latent analysis, four Structural Equation Models are implemented aiming to investigate the quantification of the impact of driver, road and traffic characteristics directly on driving performance, driver errors and accident probability.

The **theoretical background** of the described methodology is presented at the following sections.

3.2.1 Descriptive analysis

The large dataset exploited in the present research makes the **descriptive analysis** of a large number of variables essential. Within this framework, box plots (also known as a box-and-whisker charts) is a convenient way to show groups of numerical data, such as minimum and maximum values, upper and lower quartiles, median values, outlying and extreme values (Figure 3.1).

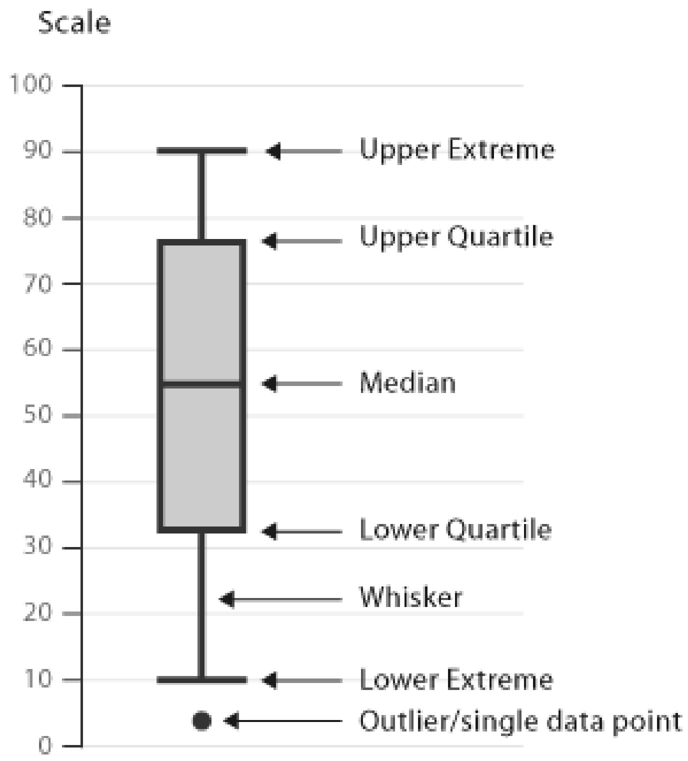

Figure 3.1 Graphical explanation of box plot

The spacing between the different parts of the box plot indicates the degree of dispersion (spread) and skewness in the data and identifies outliers. More specifically, regarding box plots:

- The line in the middle of the boxes is the median
- The bottom of the box indicates the 25th percentile. Twenty-five percent of cases have values below the 25th percentile. The top of the box represents

the 75th percentile. Twenty-five percent of cases have values above the 75th percentile. This means that 50% of the cases lie within the box.

3.2.2 Regression analysis

Linear regression is one of the most widely studied and applied statistical and econometric techniques, for numerous reasons. First, linear regression is suitable for modeling a wide variety of relationships between variables. In addition, the assumptions of linear regression models are often suitably satisfied in many practical applications. Furthermore, regression model outputs are relatively easy to interpret and communicate to others, numerical estimation of regression models is relatively easy, and software for estimating models is readily available in numerous “non-specialty” software packages. Linear regression can also be overused or misused. In some cases the assumptions are not strictly met, and suitable alternatives are not known, understood, or applied (Washington et al., 2011).

It should not be surprising that linear regression serves as an excellent starting point for illustrating **statistical model estimation** procedures. Although it is a flexible and useful tool, applying linear regression when other methods are more suitable should be avoided. This chapter illustrates the **estimation** of linear regression models, explains when linear regression models are appropriate by setting several assumptions and deals with general linear models (GLMs) as well as general linear mixed models (GLMMs).

3.2.2.1 Assumptions of linear regression models

Linear regression is used to model a **linear relationship** between a continuous dependent variable and one or more independent variables. Most regression applications seek to identify a set of explanatory variables that are thought to covary with the dependent variable. In general, explanatory or “casual” models are based on data obtained from well-controlled experiments, predictive models are based on data obtained from observational studies, and quality control models are based on data obtained from a process or system being controlled. Whether explanatory variable cause or are merely associated with changes in the dependent variable depends on numerous factors and cannot be determined on the basis of statistical modeling alone (Washington et al., 2011).

There are numerous **assumptions** (or requirements) of the linear regression model. When any of the requirements are not met remedial actions should be taken, and in some cases, alternative modeling approaches adopted. The following are the assumptions of the linear regression models (Washington et al., 2011).

- Continuous dependent variable Y
- Linear-in-parameters relationship between X and Y
- Observations independently and randomly sampled
- Uncertain relationship between variables

- Disturbance term independent of X and expected value zero
- Disturbance terms not auto-correlated
- Regressors and disturbances uncorrelated

3.2.2.2 General linear models

In statistics, the **generalized linear model** (GLM) is a flexible generalization of ordinary linear regression that allows for response variables that have error distribution models other than a normal distribution. The GLM generalizes linear regression by allowing the linear model to be related to the response variable via a link function and by allowing the magnitude of the variance of each measurement to be a function of its predicted value (Washington et al., 2011).

Generalized linear models were formulated as a way of unifying various other statistical models, including linear regression, logistic regression and Poisson regression (Hastie and Tibshirani, 1990). Hastie and Tibshirani (1990) proposed an iteratively reweighted least squares method for maximum likelihood estimation of the model parameters. Maximum-likelihood estimation remains popular and is the default method on many statistical computing packages. Other approaches, including Bayesian approaches and least squares fits to variance stabilized responses, have been developed.

A key point in the development of GLM was the **generalization of the normal distribution** (on which the linear regression model relies) to the exponential family of distributions. This idea was developed by Fisher (1934). Consider a single random variable y whose probability (mass) function (if it is discrete) or probability density function (if it is continuous) depends on a single parameter θ. The distribution belongs to the exponential family if it can be written in the form (Eq. (1)):

$$f(y;\theta) = s(y)t(\theta)e^{a(y)b(\theta)} \quad (1)$$

Where a, b, s, and t are known functions. The symmetry between y and θ becomes more evident if Eq. (1) is rewritten as Eq. (2):

$$f(y;\theta) = \exp\left[a(y)b(\theta) + c(\theta) + d(y)\right] \quad (2)$$

Where s(y)=exp[d(y)] and t(θ)=exp[c(θ)]. If a(y) =y then the distribution is said to be in the canonical form. Furthermore, any additional parameters (besides the parameter of interest θ) are regarded as nuisance parameters forming parts of the functions a, b, c, and d, and they are treated as though they were known. Many well-known distributions belong to the exponential family, including –for example– the Poisson, normal, and binomial distributions. On the other hand, examples of well-known and widely used distributions that cannot be expressed in this form are the student's t-distribution and the uniform distribution (Washington et al., 2011).

3.2.2.3 General linear mixed models

In the present research, as each drier completes several individuals driving trials, data involve **repeated measures observations** from each driver. For this purpose, generalized linear mixed models are considered.

When dealing with such panel data it is often useful to consider the heterogeneity across individuals, often referred to as unobserved heterogeneity. The generalized linear mixed model generalizes the standard linear model in three ways: accommodation of non-normally distributed responses, specification of a possibly non-linear link between the mean of the response and the predictors, and allowance for some forms of correlation in the data (Breslow and Clayton, 1993).

Finally, in order to confirm that the random effect was statistically significant, and therefore the generalized linear mixed models were superior to the respective generalized linear models, likelihood ratio test (Ben Akiva and Lerman, 1985) were performed between each set of models. The likelihood ratio test (LRT) is a statistical test of the goodness-of-fit between two models. A relatively more complex model is compared to a simpler model to see if it fits a particular dataset significantly better. If so, the additional parameters of the more complex model are often used in subsequent analyses. The LRT is only valid if used to compare hierarchically nested models. That is, the more complex model must differ from the simple model only by the addition of one or more parameters. Adding additional parameters will always result in a higher likelihood score. However, there comes a point when adding additional parameters is no longer justified in terms of significant improvement in fit of a model to a particular dataset. The LRT provides one objective criterion for selecting among possible models.

The LRT begins with a comparison of the likelihood scores of the two models:

$$LR = 2 \times (\ln L_R - \ln L_U) \quad (3)$$

Where L_R is the likelihood for the null/restricted model, while L_U is the likelihood for the alternative/unrestricted model.

This LRT statistic approximately follows a chi-square distribution. To determine if the difference in likelihood scores among the two models is statistically significant, the degrees of freedom should be investigated. In the LRT, the degrees of freedom are equal to the number of additional parameters in the more complex (unrestricted) model (Washington et al., 2011).

3.2.3 Factor analysis

In many analyses, the initial steps attempt to **uncover structure** in data that can then be used to formulate and specify statistical models. These situations arise predominately in observational settings – when the analyst does not have control over many of the measured variables, or when the study is exploratory and there are not well-articulated theories regarding the structure in the data. There are several approaches to uncovering data structure. Principal components analysis is widely used as an exploratory method for revealing structure in data. **Factor analysis**, a close relative of principal components analysis, is a statistical approach for examining the underlying structure in multivariate data. And, structural equation models (SEMs) refer to a formal modeling framework developed specifically for dealing with unobservable or latent variables, endogeneity among variables, and complex underlying data structures encountered in social phenomena often entwined in transportation applications (Washington et al., 2011).

Factor analysis is a close relative of principal components analysis. It was developed early in the twentieth century with the intent to gain insight into psychometric measurements, specifically the directly unobservable variable intelligence (Johnson and Wichern, 1992). The aim of the analysis is to reduce the number of p variables to a smaller set of parsimonious $K < P$ variables. The objective is to describe the covariance among many variables in terms of a few unobservable factors. There is one important difference, however, between principal components and factor analysis. Factor analysis is based on a specific statistical model, whereas principal components analysis is not. As was the case with principal components analysis, factor analysis relies on the correlation matrix, and so factor analysis is suitable for variables measured on interval and ratio scales.

Just as for other statistical models, there should be a theoretical rationale for conducting a factor analysis (Pedhazur and Pedhazur Schmelkin, 1991). One should not simply “feed” all variables into a factor analysis with the intention to uncover real dimensions in the data. There should be a theoretically motivated reason to suspect that some variables are measuring the same underlying phenomenon, with a subsequent examination of whether the data support this expected underlying measurement model or process.

The factor analysis model is formulated by expressing the X_i ’s as linear functions, such that,

$$
\begin{aligned}
X_1 - \mu_{1=} l_{11} F_1 + l_{12} F_2 + \dots + l_{1m} F_m + \varepsilon_1 \\
X_2 - \mu_{2=} l_{21} F_1 + l_{22} F_2 + \dots + l_{2m} F_m + \varepsilon_2 \\
\dots \\
X_3 - \mu_{3=} l_{p1} F_1 + l_{p2} F_2 + \dots + l_{pm} F_m + \varepsilon_p
\end{aligned}
$$

Where, in matrix notation the factor analysis model is given as

$$(X - \mu)_{px1} = L_{pxm} F_{mx1} + \varepsilon_{px1} \qquad (4)$$

Where F's are factors,l_{ij}’s are the factor loadings. The e_i ’s are associated only with the X_i ’s , and the p random errors and m factor loadings are unobservable or latent. With p equations and $p + m$ unknowns, the unknowns cannot be directly solved without additional information. To solve the unknown factor loadings and errors, restrictions are imposed. The types of restrictions determine the type of factor analysis model. The factor rotation method used determines the type of factor analysis model, orthogonal or oblique. Factor loadings that are either close to one or close to zero are sought. A factor loading close to one suggests that a variable X_1 is largely influenced by F_j. In contrast, a factor loading close to zero suggests that a variable X_1 is not substantively influenced by F_j. A collection of factor loadings that is as diverse as possible is sought, lending itself to easy interpretation. The orthogonal factor analysis model satisfies the following conditions:

$$\mathrm{F}, \varepsilon \text{ are independent}$$
$$E[F] = 0$$
$$COV[F] = I$$
$$E[\varepsilon] = 0$$
$$COV[\varepsilon] = \psi, \textit{ where } \psi \textit{ is a diagonal matrix}$$

Varimax rotation, which maximizes the sum of the variances of the factor loadings, is a common method for conducting an orthogonal rotation, although there are many other methods.

The oblique factor analysis model relaxes the restriction of uncorrelated factor loadings, resulting in factors that are non-orthogonal. Oblique factor analysis is conducted with the intent to achieve more interpretable structure. Specifically, computational strategies have been developed to rotate factors so as to best represent clusters of variables, without the constraint of orthogonality. However, the oblique factors produced by such rotations are often not easily interpreted, sometimes resulting in factors with less-than-obvious meaning (Washington et al., 2011).

Interpretation of factor analysis is straightforward. Variables that have high factor loadings are thought to be highly influential in describing the factor, whereas variables with low factor loadings are less influential in describing the factor. Inspection of the variables with high factor loadings on a specific factor is used to uncover structure or commonality among the variables. The underlying constructs that are common to variables that load highly on specific factors should then be determined (Washington et al., 2011).

3.2.4 Structural equation models (SEMs)

Structural equation models represent a natural extension of a measurement model, and a mature statistical modelling framework. The SEM is a tool developed largely by clinical sociologists and psychologists. It is designed to deal with several difficult modelling challenges, including cases in which some variables of interest to a researcher are unobservable or latent and are measured using one or more exogenous variables, endogeneity among variables, and complex underlying social phenomena (Washington et al., 2011).

When measurement errors in independent variables are incorporated into a regression equation (via a poorly measured variable), the variances of the measurement errors in the repressors are transmitted to the model error, thereby inflating the model error variance. The estimated model variance is thus larger than if no measurement errors are present. This outcome would have deleterious effects on standard errors of coefficient estimates, and goodness-of-fit (GOF) criteria, including the standard F- ratio and R-squared measures. If parameters are estimated using ordinary least squares then parameter estimates are biased and are a function of the measurement error variances. The SEM framework resolves potential problems by explicitly incorporating measurement errors into the modelling framework. In addition, the SEM model can accommodate a latent variable as a dependent variable, something that cannot be done in the traditional regression analysis.

3.2.4.1 Basic concept

SEM's have two 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 a number of factors or latent variables. The measurement models within a SEM incorporate estimates of measurement errors of exogenous variables and their intended latent variable. The structural model is concerned with how the model variables are related to one another. SEMs allow for direct, indirect, and associative relationships to be explicitly modeled, unlike ordinary regression techniques with implicitly model associations. It is the structural component of SEMs that enables substantive conclusions to be made about the relationship between latent variables, and the mechanisms underlying a process of phenomenon. Because of the ability of the SEMs to specify complex underlying relationships, SEMs lend themselves to graphical representations and these graphical representations have become the standard means for presenting and communicating information about SEMs (Washington et al., 2011).

Like factor and principal components analyses, SEMs rely on information contained in the variance-covariance matrix. Similar to other statistical models, the SEM requires the specification of relationships between observed and unobserved variables. Observed variables are measured, whereas unobserved variables are latent variables – similar to factors in a factor analysis – which represent underlying unobserved constructs. Unobserved variables also include error terms that reflect the portion of the latent variable not explained by their observed counterparts. In a SEM, there is a risk that the number of model parameters sought will exceed the number of model equations needed to solve them. Thus, there is a need to distinguish between fixed and free parameters – fixed parameters being set by the analyst and free parameters being estimated from the data. The collection of fixed and free parameters specified by the analyst will imply a variance-covariance structure in the data, which is compared to the observed variance-covariance matrix to assess model fit.

There are three types of relationships that are modeled in the SEM. An association is a casual (not causal) relationship between two independent variables, and is depicted as a double headed arrow between variables. A direct relationship is where the independent variable influences the dependent variable, and is shown with a directional arrow, where the direction of the arrow is assumed to coincide with the direction of influence from the exogenous to the endogenous variable. An indirect relationship is when an independent variable influences a dependent variable indirectly through a third independent variable. For example, variable *A* has a direct effect on variable *B*, which has a direct effect on variable *C*: so variable *A* has an indirect effect on variable *C*. Note that in this framework a variable may serve as both an endogenous variable in one relationship, and an exogenous variable in another.

Figure 3.2 shows a graphical representation of two different linear regression models with two independent variables, as is often depicted in the SEM nomenclature. The independent variables X_1 and X_2, shown in rectangles, are measured exogenous variables, have direct effects on variable Y_1, and are correlated with each other. The model in the bottom of the figure reflects a fundamentally different relationship among variables. First, variables X_3 and X_4 directly influence Y_2. Variable X_4 is also directly influenced by variable X_3. The SEM model shown in the top of the figure implies a different variance – covariance matrix then the model shown in the bottom of the figure. The models also show that although the independent variables have direct effects on the dependent variable, they do not fully explain the variability in Y, as reflected by the error terms, depicted as ellipses in the figure. The additional error term, error 3, is that portion of variable X_4 not fully explained by variable X_3. Latent variables, if entered into these models, would also be depicted as ellipses in the graphical representation of the SEM (Washington et al., 2011).

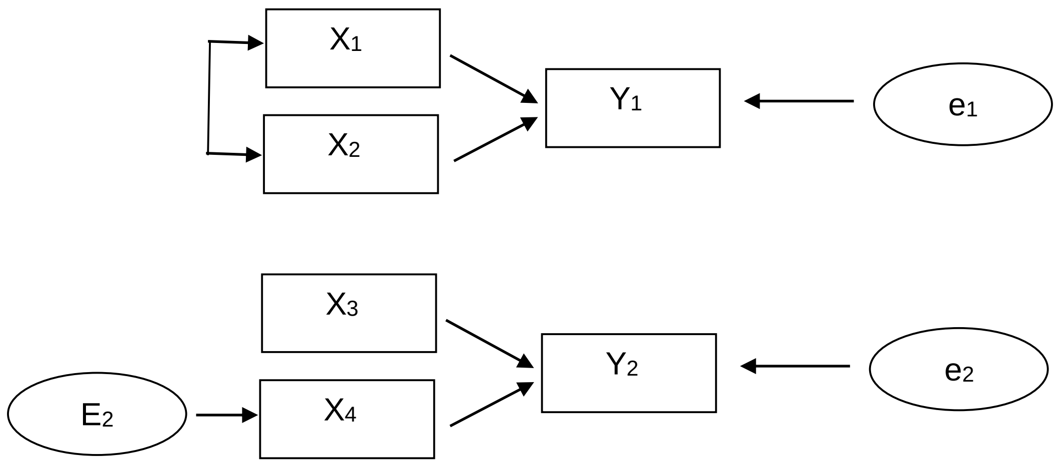

Figure 3.2 Example of SEM

An obvious issue of concern is how these two different SEMs depicted in Figure 3.2 imply different variance-covariance matrices. The model depicted in the top of Figure 3.2 represents a linear regression model with two independent variables that covary, such that $Y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + error_1$. The model depicted in the bottom of the figure represents two simultaneous regressions, $Y_2 = \beta_0 + \beta_3 X_3 + \beta_4 X_4 + error_2$ and $X_4 = \beta_0 + \beta_5 X_3 + error_3$. In this second SEM model, the variable X_4 serves as both exogenous and an endogenous variable. The collective set of constraints implied by these two SEMs determines the model implied variance-covariance structure. The original correlation matrix is completely reproduced if all effects, direct, indirect, and correlated, are accounted for in a model. This saturated model is uninteresting simply because there is no parsimony achieved by such a model. Without compromising the statistical validity of the model, a natural goal is to simplify an underlying complex data generating process with a relatively simple model. How the path is drawn in the development of SEMs determines the presumed variance-covariance matrix.

3.2.4.2 Fundamentals of structural equation modeling

The focus here is to provide a general framework of SEMs, to demonstrate how the parameters are estimated, and to illustrate how results are interpreted and used.

Structural equation models, similar to other statistical models, are used to evaluate theories or hypotheses using empirical data. The empirical data are contained in a $P \times P$ variance-covariance matrix S, which is an unstructured estimator of the population variance-covariance matrix Σ. A SEM is then hypothesized to be a function of Q unknown structural parameters (in parameter vector θ), which in turn will generate a model-implied variance-covariance matrix $\Sigma(\theta)$. All variables in the model, whether observed or latent, are classified as either independent (endogenous) or dependent (exogenous). A dependent variable in a SEM diagram is a variable that has a one-way arrow pointing to it. The set of these variables is collected into a vector η, while independent variables are collected in the vector ξ, such that (Bentler and Weeks, 1980).

$$\eta = \beta\eta + \gamma\xi + \varepsilon \qquad (5)$$

Where β and γ are estimated vectors of coefficients that contain regression coefficients for the dependent and independent variables, respectively, and ε is a vector of regression errors. The exogenous factor covariance matrix is represented as $\Phi = COV\,[\varepsilon, \varepsilon^T]$, and the error covariance matrix as $\psi = COV\,[\varepsilon, \varepsilon^T]$. The variance-covariance matrix for the model in Equation 5 is

$$\Sigma(\theta) = G\,(I-\beta)^{-1}\,\gamma\,\Phi\,\gamma^T\,(I-\beta)^{-1T}\,G^T \qquad (6)$$

Where G is a selection matrix containing either 0 or 1 to select the observed variables from all the dependent variables in η. There are P^2 elements or simultaneous equations in Equation 6, one for each element in $\Sigma(\theta)$. Some of the P^2 equations are redundant, however, leaving $P^* = P(P-1)/2$ independent equations. These P^* independent equations are used to solve the unknown parameters θ, which consist of the vector β, the vector γ, and Φ. The estimated model-implied variance-covariance matrix is then given as Σ(θ).

Model identification in SEM can present serious challenges. There are Q unknown model parameters (comprising θ), which must be solved using P^* simultaneous independent equations. There are two necessary and sufficient conditions for SEM identification. The first is that the number of simultaneous equations must be equal to or greater than the number of unknown model parameters, such that $Q \leq P^*$. The second is that each and every free model parameter must be identified, which often is difficult (Hoyle, 1995).

Once the SEM has been specified, and identification conditions are met, solutions for the parameters are obtained. Parameters are estimated using a discrepancy function criterion, where the differences between the sample variance-covariance matrix and the model-implied variance-covariance matrix are minimized. The discrepancy function is

$$F = F\,(S, \Sigma(\theta)) \qquad (7)$$

Different estimation methods in SEM have varying distributional assumptions, and in turn require different discrepancy functions. For example, maximum likelihood (MLE) estimated model parameters, which requires that specific distributional and variable assumptions are met, are obtained using the discrepancy function

$$F_{MLE} = LN\,|\Sigma\,(\theta)\,| + TRACE\,[\Sigma(\theta)^{-1}\,S] - LN\,|S|\; -p \qquad (8)$$

For detailed discussions on other discrepancy functions and corresponding estimation methods, including MLE, generalized least squares (GLS), asymptotically distribution-free (ADF), scale-free least squares (SLS), unweighted least squares (ULS), and Browne's method (Arbuckle and Wothke ,1995; Hoyle ,1995; Arminger et al., 1995).

A useful feature of discrepancy functions is that they are useful for testing the null hypothesis that H_0: $\Sigma(\theta) = \Sigma$, where

$$X^2 = F\,(n-1) = \chi^2\,(\alpha, P^* - Q) \qquad (9)$$

This equation shows – given that the model is correct, variables are approximately multivariate normally distributed, and the sample size is sufficiently large – that the product of the minimized discrepancy function and sample size minus one is asymptotically chi-square distributed with degrees of freedom equal to P^*-Q. Also, it is g straightforward to show that SEM parameter estimates are asymptotically unbiased, consistent, and asymptotically efficient (Hoyle, 1995).

Equation 9 needs to be applied with care. Its unsuitability as a criterion for model assessment and selection was pointed out early in SEM theory development because the test statistic is largely a function of sample size (Bentler and Bonett, 1980; Gullikson and Tukey, 1958; Joreskog,1969). Thus, the X^2 best serves the analyst in the selection of the best from competing models estimated on the same data, and whose absolute value should be evaluated with respect to sample size on which the statistic is estimated.

3.2.4.3 Non-ideal conditions

As previouelsy mentioned, ideal conditions in SEM include multivariate normality of independent variables, the correct model functional form, independent and dependent variables measured on the interval or ratio scale, and a sufficiently large sample size. A large number of studies have been conducted to assess the impact of continuous yet non-normal variables on SEMs (Browne, 1984; Chou et al., 1991; Finch et al., 1994; Hu et al., 1992; Kline, 1998). Non-normality can arise from poorly distributed continuous variables or coarsely categorized continuous variables. Non-normality is detected in a number of ways, including box plots, histograms, normal probability plots, and by inspection of multivariate kurtosis. Numerous studies have arrived at similar conclusions regarding the impact of non-normality in SEMs. The X^2 test statistic becomes inflated as the data become more non-normal. In addition, the GLS and MLE methods of parameter estimation produce inflated X^2 test statistics with small sample sizes, even if multivariate normality is satisfied. In addition, model GOF indices are underestimated under non-normality and non-normality leads to moderate to severe underestimation of standard errors of parameter estimates.

There are several remedies for dealing with non-normality. The asymptotically distribution-free estimator (ADF) is a GLS estimation approach that does not rely on multivariate normality (Browne, 1984). The ADF estimator produces asymptotically unbiased estimates of the X^2 test statistic, parameter estimates, and standard errors. The scaled X^2 test statistic, developed by Satorra and Bentler (Satorra, 1990), corrects or rescales the X^2 test statistic so that it approximates the referenced χ^2 distribution.

Bootstrapping is a third method for dealing with non-normal samples. Bootstrapping is based on the principle that the obtained random sample is a fair representation of the population distribution, and by resampling from this sample, estimates of parameters and their standard errors obtained are reliable estimates of the true population parameters. Efron and Tibshirani (1986) have demonstrated that in many studies the sampling distribution is reasonably approximated by data obtained from a single sample. Details of the bootstrap approach to SEM is provided in Bollen and Stine (1992).

Nominal and ordinal scale variables also cause problems in SEMs – resulting in biased estimates of X^2 test statistics and estimated parameters and their standard errors. One approach, developed by Muthen (1984), consists of a continuous/categorical variable methodology (CVM) weighted least squares estimator and discrepancy function, which results in unbiased, consistent, and efficient parameter estimates when variables are measured on nominal and ordinal scales. However, this estimator requires large sample sizes (at least 500-1.000 cases), and is difficult to estimate for overly complex models (Hoyle, 1995). Other approaches include variable re-expressions (Cattell and Burdsal

1975), variable transformations (Daniel and Wood 1980; Emerson and Stoto 1983), and alternating conditional expectations and Box-Cox transformations (De Veaux, 1990).

Interactions and nonlinear effects arise frequently in the modeling of real data. In SEM, interactions and nonlinear effects present challenges above and beyond those encountered in simple linear regression. There are two general approaches to handling these problems; the indicant product approach, and the multisample approach. The indicant product approach is only well developed for multiplicative cases, and requires a centering transformation. The multisample approach is more flexible, avoids some multicollinearity and distributional problems associated with the product indicant approach, and is suitable under the widest range of conditions (Rigdon et al., 1998). Most currently available SEM software packages can accommodate the multisample approach.

3.2.4.4 Model goodness-of-fit measures

Model *Goodness-of-Fit* measures are an important part of any statistical model assessment. GOF measures in SEMs are an unsettled topic, primarily as a result of lack of consensus on which GOF measures serve as “best” measures of model fit to empirical data (Arbuckle and Wothke, 1995). Several researches are implemented discussing these debates and a multitude of SEM GOF methods such as Mulaik et al., (1989), MacCallum (1990), Steiger (1990), Bollen and Long (1993), Arbuckle and Wothke (1995).

Several important concepts are routinely applied throughout SEM GOF tests that enable the assessment of statistical models. A saturated model is a model that is perfectly fit to the data – the variance-covariance structure is completely unconstrained and represents an unappealing model. It is the most general model possible, and is used as a standard of comparison to the estimated model. Because the saturated model is as complex as the original data, it does not summarize the data into succinct and useful relationships. In contrast, the independence model is constrained such that no relationships exist in the data and all variables in the model are independent of each other. This model presents the “worst case” model. The saturated and independence models are typically viewed as two extremes within which the best model lies.

There are a large number of GOF criteria available for assessing the fit of SEMs. Several important and widely used GOF measures are described below, however the majority of them can be found in the references provided.

The first class of GOF indices includes measures of parsimony. Models with few parameters are preferred to models with many parameters, providing that the important underlying model assumptions are not violated. This modeling philosophy is born by a general desire to explain complex phenomena with as simple a model as possible. Three simple measures of parsimony are the number of model parameters Q, the degrees of freedom of the model being tested df = $P^* - Q$ and the parsimony ratio

$$PR = \frac{\mathrm{d}}{\mathrm{d}_1} \quad (10)$$

where d is the degrees of freedom of the estimated model and d_1 is the degrees of freedom of the independence model. The *PR* represents the number of parameter constraints of the estimated model as a fraction of the number of constraints in the independence model (a higher *PR* is preferred).

There are several GOF indices based on the discrepancy function *F*. As stated previously, the χ^2 test statistic, derived from the discrepancy function, needs to be treated with care because it is dependent largely on sample sizes – small samples tending to accept (fail to reject) the null hypothesis, and large samples tending to reject the null hypothesis.

The X^2 statistic is the minimum value of the discrepancy function *F* times its degrees of freedom (see equation 9). The *p*-value is the probability of obtaining a discrepancy function as large as or larger than the one obtained by random chance if the model is correct, distributional assumptions are correct and the sample size is sufficiently large. The statistic X^2 /(model degrees of freedom) has been suggested as a useful fit measure. Rules of thumb have suggested that this measure (except under ULS and SLS estimation) should be close to 1 for correct models. In general, it is recommended that this statistic should lie less than 5, with values close to 1 being preferred (Byrne, 1989; Carmines and McIver, 1981; Marsh and Hocevar, 1985).

Another class of fit measures is based on the population discrepancy. These measures rely on the notion of a population discrepancy function (as opposed to the sample discrepancy function) to estimate GOF measures, including the noncentrality parameter (NCP), the root mean square error of approximation (RMSEA), and PCLOSE, the *p*-value associated with a hypothesis test of RMSEA ≤ 0.05. For details on these measures the reader should consult Steiger et al. (1985) and Browne and Cudeck (1993).

Information theoretic measures are designed primarily for use with MLE methods, and are meant to provide a measure of the amount of information contained in a given model. There are many measures used to assess fit in this class. The Akaike information criterion (Akaike, 1987) is given as

$$AIC = 2Q - 2LL(\theta) \quad (11)$$

where Q is the number of parameters and $LL(\theta)$ is the log-likelihood at convergence. Lower values of AIC are preferred to higher values because higher values of $-2LL(\theta)$ correspond to greater lack of fit. In the AIC criterion a penalty is imposed on models with larger numbers of parameters, similar to the adjusted *R*-square measure in regression. The Browne-Cudeck (1989) criterion is similar to AIC, except it imposes a slightly greater penalty for model complexity than does AIC. It is also the only GOF measure in this class of measures designed specifically for the analysis of moment structures (Arbuckle and Wothke, 1995).

Other GOF measures in this category include the relative fit index (RFI), the incremental fit index (IFI), the Tucker-Lewis coefficient, and the comparative fit index (CFI), discussion on which is found in Bollen (1986), Bentler (1990), and Arbuckle and Wothke (1995).

3.3 Synopsis of methodology

The present PhD thesis aims to investigate the effect of road, traffic and driver risk factors on driver behaviour and road safety. Within this framework, one of the main objectives of the overall research is the development of an **innovative statistical analysis methodology** in the field of driver distraction. This methodology is based on two literature reviews regarding driving performance measures and statistical analysis methods. From these complementary reviews several specific conclusions are extracted and presented here-in:

Regarding driving performance measures the respective review presented in this chapter revealed that:

- Driver distraction is a multidimensional **phenomenon** which means that no single driving performance measure can capture all effects of distraction.
- A lot of different methods and measures exist for evaluating driving performance the most common of which include lateral control, longitudinal control, reaction time, gap acceptance, eye movement and workload measures.
- **The selection of the specific measures should be guided by the nature of the task examined as well as the specific research questions.**

The review on statistical analysis methods examining driver distraction (presented in this and the previous chapter) demonstrated that:

- 5% of the examined studies perform only **descriptive** statistics tests aiming to gain general information regarding different performance measures.
- More than half of the examined studies perform **repeated** measures Anova which is explained by the fact that in most driving simulator experiment participants are asked to drive more than one trials.
- **Latent model analysis and especially structural equation models have never been implemented in the field of driver distraction.**

Based on these literature reviews the statistical analysis research questions of the present PhD thesis focused to:

- the investigation of the effect of road, traffic and driver risk factors such as age, gender, area and traffic conditions on different distracted situations on selected driving performance measures,
- the estimation of the effect of distraction sources and driving characteristics on specific driving performance parameters and indirectly on driving behaviour and road safety

- the implementation of a novelty new statistical analysis in the field of driver distraction

In order to answer the above research question an innovative statistical analysis methodology has been developed, the theoretical background of which was presented in the present chapter. More specifically, the overall statistical methodology is consisted of four steps:

In the first step, **descriptive analysis** is taking place in order to explore of a large number of variables essential. In this framework, an overview picture of all variables that are provided by the driving simulator is provided.

Then, in the framework of the explanatory analysis, the development of **regression models** is taking place in order to estimate the effect of distraction sources and driving characteristics on specific driving performance parameters and indirectly on driving behaviour and road safety.

In the next step, **factor analysis** is implemented regarding driving performance and driver errors in order to investigate which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the data.

Finally in the fourth step, the central point of the statistical analysis of the present PhD thesis is taking place including the implementation of structural equation models for the **first time** in the scientific field of driver distraction. Within the framework of latent analysis, four **Structural Equation Models are implemented aiming to investigate** the quantification of the impact of driver distraction, driver characteristics and road environment **directly** on driving performance, driver errors and accident risk.

4. Driving simulator experiment

A central component of the present PhD thesis is the **design** and **implementation** of a large driving simulator experiment. Based on the methodology review which was carried out and presented in the previews chapters, a large driving simulator experiment took place at the Department of Transportation Planning and Engineering of the School of Civil Engineering of the National Technical University of Athens aiming to assess distracted driving performance.

The **objective** of the present chapter is to present the experiment design both in terms of conceptual framework and implementation as well to record basic parameters regarding the data storage/processing and sample characteristics.

In the beginning, an **overview of the driving simulator experiment** is taking place including details regarding the interdisciplinary research teams who contributed in the design of the experiment. Furthermore, several other information are provided concerning driving simulator characteristics, sample characteristics, the exclusion criteria as well as how researchers deal with the phenomenon of simulator sickness.

In the next chapter, the **design** of the driving simulator experiment is deeply investigated as it constitutes an innovating component of the PhD thesis. Participants were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in different road (urban/rural) and traffic conditions (high/moderate). In this framework, all these conditions are analysed and the full factorial within-subject design is presented. Furthermore, several other relevant aspects of the design are provided concerning conversation topics, incidents, and randomisation of trials as well as how the driving simulator scenarios were programmed.

Then, the **procedure** of the driving simulator experiment is presented. More specifically, the organisation of the research team is provided and the oral instructions to the participants are recorded. Furthermore, special emphasis is given to the familiarisation part, as specific performance measures were used to assess the driver's familiarisation with the simulator before proceeding to the main part of the experiment. Then, the process of the main driving scenarios is described.

In the next part of the experiment, following the completion of the driving simulator tasks, participants were asked to fill in two **questionnaires**. The first Questionnaire concerned their driving habits and their driving behaviour while the second was a Self-Assessment Questionnaire that covered aspects related to the driving simulator experience. In this section, all the different parts as well as indicative questions of each questionnaire are presented.

Finally, as the dataset form the driving simulator experiment and the questionnaires is extremely large, information regarding the **data processing** are provided including data files, data storage and the processing levels, while characteristics regarding the **sample** are provided.
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4.1 Overview of the experiment

The driving simulator experiment of the present PhD study was carried out in the framework of **two interdisciplinary research projects**.

- The **DISTRACT** research project, entitled "Analysis of causes and impacts of driver distraction", aimed to analyse endogenous and exogenous causes of driver inattention and distraction and their impacts on driver behaviour and safety.
- The **DriverBrain** research project, entitled "Analysis of the performance of drivers with cerebral diseases", aimed to analyse driving performance of drivers with cerebral diseases including cerebral incidents, Parkinson, Alzheimer, Dementia and Mild Cognitive Impairment.

For the purpose of these two research projects, three research teams had contributed in the design of the driving simulator experiment as well as in the respective questionnaires. The whole research team was consisted of:

- Transportation Engineers of the Department of Transportation Planning and Engineering, of the National Technical University of Athens (NTUA),
- Neurologists of the 2nd Department of Neurology, University of Athens Medical School, at ATTIKON University General Hospital, Haidari, Athens.
- Neuropsychologists of the Department of Psychology, University of Athens, the 2nd Department of Neurology of ATTIKON University General Hospital, Haidari, Athens and the Aristotle University of Thessaloniki.

Within this framework, a driving simulator experiment was carried out, in which **95 participants** were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in different road (urban/rural) and traffic conditions (high/low).

Each participant aimed to complete 12 different driving trials, while in each trial, 2 unexpected incidents were scheduled to occur at fixed points along the drive. Then, participants were asked to fill in two **questionnaires** regarding their driving behaviour, as well as self-assessment and memory tests.

The above stages were designed on the basis of parameters and criteria shown to be important in the literature, as well as **design principles** that were appropriate for the research assumptions and objectives of the present research. These are presented in the following sections.

This chapter is **structured** as follows. In the beginning, details regarding the driving simulator in which the experiment was carried out are provided. Then, the exclusion criteria are recorded while the crucial phenomenon of simulator sickness is explored.

4.1.1 Driving simulator

The **driving simulator experiment** took place at the special room of the Laboratory of Traffic Engineering of the Department of Transportation Planning and Engineering of the School of Civil Engineering of the National Technical University of Athens (NTUA), where the FOERST Driving Simulator FPF is located.

The Foerst GmbH is a DIN ISO 9001-certified company while the simulator used in the current experiment has been manufactured by the FOERST Company in order to serve research purposes. The following photo is presenting the driving simulator which consists of 3 LCD wide screens 40'' (full HD), total angle view 170 degrees, driving position and support base. The dimensions at a full development are 230x180 cm. with a base width of 78cm.

Figure 4.1 Experimental Driving Simulator

It features adjustable driver seat, steering wheel 27cm diameter, pedals (throttle, brake, clutch), dashboard and two external and one central mirror that appear on the side and on the main screen, and display in real time objects and events that are happening behind the 'vehicle'. The controls available to the driver are: 5 gears plus reverse gear, flash, wipers, lights, horn, brake and starter.

The **virtual road environment** is generated by the computer and displays the road environment. Users can drive along the road under realistic conditions. It is highlighted that driving conditions in the simulator cannot be absolutely identical to those perceived by the driver in real driving, but the change of the driver behaviour does not necessarily affect the relative influence of various parameters.

Moreover, in the specific driving simulator it is possible to simulate many conditions between alternative types of roads (urban-interurban road, highway), in different traffic conditions (normal - less - without - just oncoming traffic), and under different environment (good weather, fog, rain, snow, night). Furthermore, according to the experimental requirements, **dangerous situations** like unexpected appearance of an animal during driving, or unexpected course of a leading vehicle at predetermined or random points along the route were selected.

4.1.2 Exclusion criteria

People who participated in the present experiment met certain basic **criteria based** on an examination of neurologists and neuropsychologists. The detailed form is attached in Annex 1. Each participant should:

- Have a valid driving license
- had driven for more than 3 years
- had driven more than 2500km during the last year
- had driven at least once a week during the last year
- had driven at least 10km/week during the last year
- not had important psychiatric history for psychosis
- not had any important kinetic disorder that prevent them from basic driving moves
- not had dizziness or nausea either as a driver or as a passenger
- not be pregnant
- not be an alcoholic or had any other drug addiction
- not had any important eye disorder that prevent him from driving safely
- not had any disease of the Central Nervous System

In case one participant failed even in one of the above criteria, he was eliminated from the experiment from carrying out the experiment.

4.1.3 Dealing with simulator sickness

Simulator sickness is a phenomenon that is affected by simulator features and participant characteristics. It produces symptoms that are similar to, but typically less severe than those of motion sickness such as nausea, ocular discomfort, and disorientation (Kennedy et al., 1993).

It was possible, during and after the pilot driving, that the driver felt a mild or intense discomfort, dizziness or nausea. In that case, the coordinator asked the participant if he could carry on with the experiment. In case of a negative answer, it was essential that the experiment stopped. If the driver answered positively the experiment continued following an adequate brake, so that the participant felt better. In case the participant was not willing to continue, or reported - or was suspected to - experience more severe symptoms, the experiment was cancelled.

4.1.4 Driving simulator validation

Simulator validity refers to the degree to which behaviour in the simulator corresponds to behaviour in real-world environment under the same conditions (Kaptei et al., 1996; 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).

In order to investigate the validity of the present driving simulator another similar research took place. The objective of this research was 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 in the region of Paiania.

Figure 4.2 Driving simulator and on road experiment

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. Regarding 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.

4.2 Driving scenarios

The **design** of the driving simulator experiment constitutes an **innovating component** of the PhD thesis, considering that all individual parts are carefully designed based on limitations and needs of similar driving simulators that were reviewed in the previous chapters.

In this framework, this section presents **all individual parts** of the design of driving scenarios. First, trials characteristics such as area type and traffic conditions are analysed and the distraction sources are examined. Then, special emphasis is given on the overall experiment design since within- and between-subjects designs are presented, and the full factorial or fractional factorial design implemented is further analysed. Furthermore, several other relevant aspects of the design are provided, with regard to conversation topics, incidents, randomization of trials and concerning in what way the scenarios were programmed.

4.2.1 Area type conditions

In the framework of the present experiment two routes had been developed in order to estimate the effect of area type on distracted driving performance. More specifically a **divided urban arterial** and an **undivided two-lane rural road** correspond to different road environments (inside / outside urban areas).

- The **rural route** was 2,1 km long, single carriageway and the lane width was 3m, with zero gradient and mild horizontal curves.

- The **urban route** was 1,7km long, at its bigger part dual carriageway, separated by guardrails, and the lane width was 3,5m. Moreover, narrow sidewalks, commercial uses and parking were available at the roadsides while two traffic controlled junctions, one stop-controlled junction and one roundabout were placed along the route.

Figure 4.2 shows the **horizontal design** of the road in the two different sessions. It is worth mentioning that a programming code has been developed in order to generate specific routes from the variety of maps available in the simulator software.

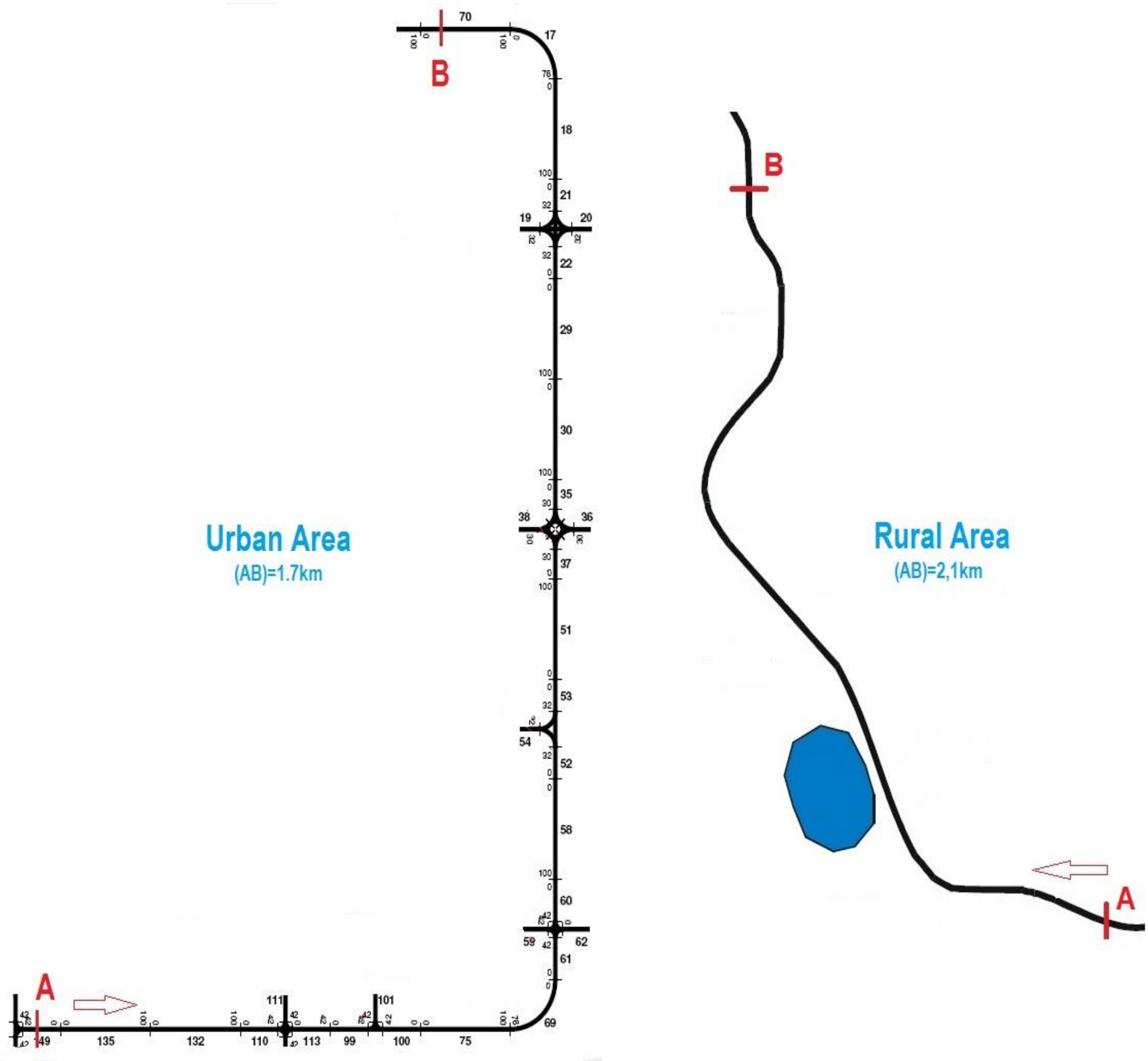

Figure 4.3 Urban and rural routes

4.2.2 Traffic scenarios

The effect of **traffic flow** on distracted driving is a key research parameter of the present research. The simulation of ambient traffic (i.e. the behavior of other vehicles on the simulated road network) may be a very complex task. In some cases, the interest might be in simulating in detail the behavior of no more than one or two vehicles in relation to the simulator vehicle. In other cases, such as in the present research, the interest might be in the “global” traffic conditions experienced by the participant during the simulated drive.

However, it should be acknowledged that the simulation of **ambient traffic** in driving simulators is much more demanding than classical traffic microsimulation, for the reason that it should be implemented in a ‘moving window’ framework, similarly to the driving simulator. In fact, the simulated environment is not static. The traffic flow parameters of the ambient traffic need to be specified in relation to the traffic parameters of the ‘moving’ simulator vehicle in the virtual environment, and within the limits of the ‘window’ corresponding to the screen view provided to the simulator driver. Most traffic microsimulation models are not appropriate under these conditions, and the researcher is requested to program his / her own traffic scenarios.

Recently, a promising **approach** was proposed by Olstam (2003) according to which, vehicles moving ‘inside’ the ‘moving window’ may be simulated in more detail, in accordance with sophisticated traffic micro-simulation or car-following models, whereas other vehicles in the simulated network – but ‘outside’ the moving window can be simulated probabilistically i.e. drawn from appropriate statistical distributions.

Within the present research, a key parameter is the traffic volume experienced by the driver, under the assumption that higher traffic volume may further impair distracted driving. Consequently, the behavior of specific vehicles, or their response to driver behaviour, is not a priority for the experiment design – and can be covered by the default traffic behavior features of ambient traffic in the simulator. Therefore, a **probabilistic simulation** of traffic conditions was opted for, and two traffic scenarios were examined:

- **Q_M: Moderate traffic conditions** - ambient vehicles’ arrivals were drawn from a Gamma distribution with mean m=12sec, and variance σ^2=6 sec, corresponding to an average traffic volume Q=300 vehicles/hour

- **Q_H: High traffic conditions** - ambient vehicles’ arrivals were drawn from a Gamma distribution with mean m=6sec, and variance σ^2=3 sec, corresponding to an average traffic volume of Q=600 vehicles/hour

These **traffic arrivals** 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 opted for post-pilot testing various alternative combinations of distribution parameters with respect to theoretical and practical issues, including the simulated result on the virtual screen. In Figure 4.3 the gamma distributions for simulated vehicle arrivals under moderate (right panel) and high (left panel) traffic flow scenarios are presented.

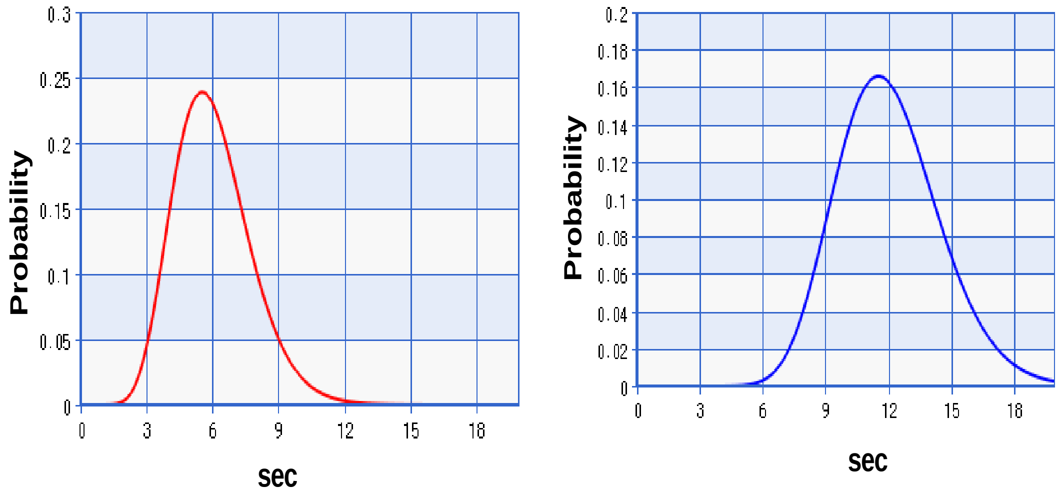

Figure 4.4 Gamma distributions for simulated vehicle arrivals

4.2.3 Distraction scenarios

After reviewing the literature, two distraction conditions were found to be more critical with respect to driver behavior and safety:

- **cell-phone conversation**
- **conversation with passenger**

Consequently, the distracted driving scenarios of the simulated experiment will be based on these in-vehicle distraction causes. The two figures below show the respective distraction scenarios - conversation with passenger and using the cell phone.

Figure 4.5 Conversation with the passenger

Figure 4.6 Conversation on the cell phone

4.2.4 Conversation topics

As already mentioned, each trial corresponds to different driving distractor and different area type and traffic volume. The trials that demand conversation as a distractor were covered by the following **topics**:

- Family
- Origin
- Accommodation
- Travelling
- Geography
- Interests
- Hobbies
- Everyday life
- News
- Business

One researcher was responsible for performing the distraction tasks during the experiment: the conversation task and the phone call with the participant, as will be explained in the following chapter regarding the overall procedure of the experiment.

4.2.5 Scenarios design

The stages of the experimental design revealed a **critical design question**: "Will each participant drive under all conditions, or will the drivers be randomly split up, so that e.g. half of them drive in one condition and the other half in another?" In statistical terminology, this question is asking whether a study should be within-subject design or a between-subject design.

Within-subject factors refer to the variables of interest that are measured for all subjects, i.e. the variables pertaining to the experiment conditions. On the other hand, **between-subject factors** refer to the variables that apply only to some subjects. With regard to the driving simulator experiment, these are typically subject variables, such as demographic variables and participant type where part of the subjects are tested for some of the experiment conditions, while the rest of the subjects are tested for the remaining experiment conditions. In several cases, a mixture of both types of design will be involved, given that there are variables which are by nature between-subject (e.g. gender, as a participant can be either male or female) while others can be within-subject (e.g. driving with distraction or without distraction – a condition that can be tested for all subjects). A mixed factorial design includes both within-subjects and between-subjects factors.

The main **advantage** of **within-subject** design is that tends to increase statistical power. Furthermore, there are several within-subject variables in the present experiment (e.g. driver characteristics). Therefore, a within-subject design was opted for the driving simulator experiment.

Moreover, a **full factorial within-subject design** was selected in this research as shown in Table 4.1. Full factorial or fractional factorial design means that each experiment is based on a synthesis 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. However, in several cases a fractional factorial design may be opted for, by eliminating some of the combinations of levels of the variables examined, on the basis of appropriate criteria (McLean and Anderson, 1984), especially when the number of variables is high, resulting to an unmanageable full factorial design. More specifically, a fractional factorial design is most often based on a full factorial design of some key variables of interest, complemented with selected combinations of these variables with other variables of interest (Montgomery, 2000).

This design was determined after examining various full or fractional factorial design alternatives (e.g. including night-time, or adverse weather driving conditions), and was finalized after the careful selection of **key research parameters**.

Table 4.1 Within-subject full factorial design parameters

	Road Traffic Conditions			
	Urban Area		Rural Area	
Distraction Sources	$Q_{Moderate}$	Q_{High}	$Q_{Moderate}$	Q_{High}
No Distraction	√	√	√	√
Cell Phone	√	√	√	√
Conversation With Passenger	√	√	√	√

Consequently there were 2 driving sessions with up to 6 trials each (Table 4.2), which were randomized between and within sessions. Is should be noted that whenever a participant claimed that he, or she, does not use a cell phone while driving under any circumstances, the 4 trials that include cell-phone distraction were subtracted.

Table 4.2 Sessions and trials characteristics

Session	Area Type	Trial	Traffic	Distractor	~ Length (Km)
1	Urban	1	Moderate	None	1,7
		2	High	None	1,7
		3	Moderate	Cell Phone	1,7
		4	High	Cell Phone	1,7
		5	Moderate	Conversation	1,7
		6	High	Conversation	1,7
2	Rural	7	Moderate	None	2,1
		8	High	None	2,1
		9	Moderate	Cell Phone	2,1
		10	High	Cell Phone	2,1
		11	Moderate	Conversation	2,1
		12	High	Conversation	2,1
				Total	**22,8**

4.2.6 Incidents

During each trial of the experiment, 2 **unexpected incidents** were scheduled to occur at fixed points along the drive (but not at the exact same point in all trials, in order to minimize learning effects). More specifically, incidents in rural area concerned the sudden appearance of an animal (deer or donkey) on the roadway, and incidents in urban areas concerned the sudden appearance of an adult pedestrian or of a child chasing a ball on the roadway.

Figure 4.7 Unexpected incident - donkey crossing the lane

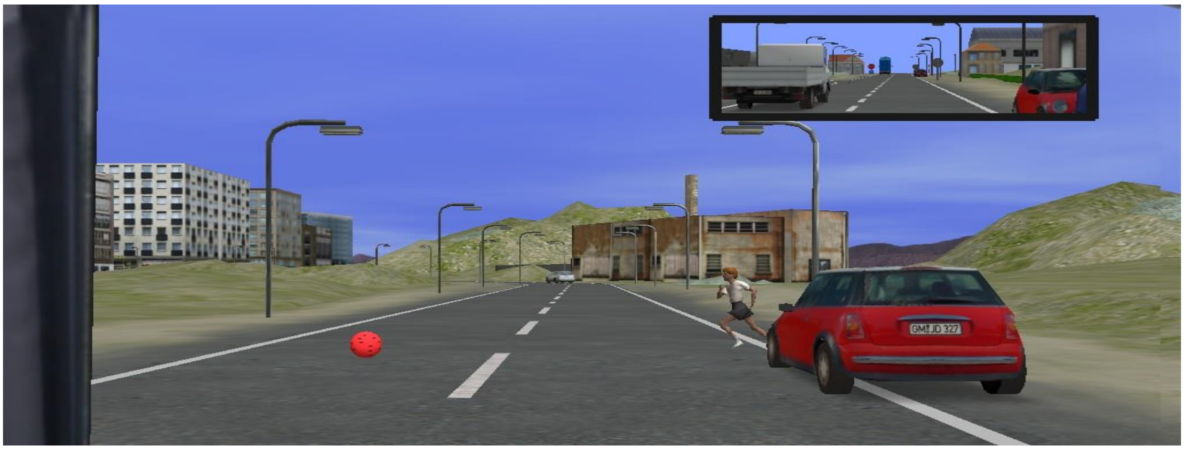

Figure 4.8 Unexpected incident - child with ball crossing the road

4.2.7 Randomisation

The first principle of an experimental design is **randomization**, which is a random process of assigning treatments to the experimental units. The random process implies that every possible allotment of treatments has the same probability. An experimental unit is the smallest division of the experimental material and a treatment refers to an experimental condition whose effect is to be measured and compared. The purpose of randomization is to remove bias and other sources of extraneous variation, which are not controllable. Another advantage of randomization (accompanied by replication) is that it forms the basis of any valid statistical test (Boyle, 2011). Hence the treatments must be assigned at random to the experimental units. Randomization is usually done by drawing numbered cards from a well-shuffled pack of cards, or by drawing numbered balls from a well-shaken container or by using tables of random numbers.

In this experiment randomization was implemented in the order of **area type** (urban/rural) in which the participant was going to drive, as well as in the order of the **traffic scenarios** and **distraction scenarios**. Nevertheless, it was concluded that full randomization would not be meaningful, as a huge number of combinations would be obtained, thus a limited number of combinations for each variable were selected. More specifically:

The possible orders of the traffic scenarios selected for the 6 trials were:

- $\mathbf{Q_M\text{-}Q_M\text{-}Q_M\text{-}Q_H\text{-}Q_H\text{-}Q_H}$
- $\mathbf{Q_H\text{-}Q_H\text{-}Q_H\text{-}Q_M\text{-}Q_M\text{-}Q_M}$
- $\mathbf{Q_M\text{-}Q_H\text{-}Q_M\text{-}Q_H\text{-}Q_M\text{-}Q_H}$
- $\mathbf{Q_H\text{-}Q_M\text{-}Q_H\text{-}Q_M\text{-}Q_H\text{-}Q_M}$

Where:
Q_M: Moderate traffic
Q_H: High traffic

Randomization was also applied in the order that the distraction sources were examined in the 6 trials:

- **NO-CONV-MOB**
- **NO-MOB-CONV**
- **MOB-NO-CONV**
- **MOB-CONV-NO**
- **CONV-NO-MOB**
- **CONV-MOB-NO**

Where
NO: No distraction
MOB: Cell phone
CONV: Conversation with passengers

These scenarios were randomly assigned to participants (Table 4.3) in a counterbalanced way, so that eventually equal proportions of similar groups of participants were assigned to each scenario. One researcher was responsible for the correct counterbalancing of the trial's order.

Table 4.3 Randomised trials' order

Selected orders						
1	Q_M-No	Q_M-Mob	Q_M-Conv	Q_H-No	Q_H-Mob	Q_H-Conv
2	Q_M-No	Q_M-Conv	Q_M-Mob	Q_H-No	Q_H-Conv	Q_H-Mob
3	Q_M-Conv	Q_M-Mob	Q_M-No	Q_H-Conv	Q_H-Mob	Q_H-No
4	Q_M-Conv	Q_M-No	Q_M-Mob	Q_H-Conv	Q_H-No	Q_H-Mob
5	Q_M-Mob	Q_M-Conv	Q_M-No	Q_H-Mob	Q_H-Conv	Q_H-No
6	Q_M-Mob	Q_M-No	Q_M-Conv	Q_H-Mob	Q_H-No	Q_H-Conv
7	Q_H-No	Q_H-Mob	Q_H-Conv	Q_M-No	Q_M-Mob	Q_M-Conv
8	Q_H-No	Q_H-Conv	Q_H-Mob	Q_M-No	Q_M-Conv	Q_M-Mob
9	Q_H-Conv	Q_H-Mob	Q_H-No	Q_M-Conv	Q_M-Mob	Q_M-No
10	Q_H-Conv	Q_H-No	Q_H-Mob	Q_M-Conv	Q_M-No	Q_M-Mob
11	Q_H-Mob	Q_H-Conv	Q_H-No	Q_M-Mob	Q_M-Conv	Q_M-No
12	Q_H-Mob	Q_H-No	Q_H-Conv	Q_M-Mob	Q_M-No	Q_M-Conv
13	Q_M-No	Q_H-No	Q_M-Mob	Q_H-Mob	Q_M-Conv	Q_H-Conv
14	Q_M-No	Q_H-No	Q_M-Conv	Q_H-Conv	Q_M-Mob	Q_H-Mob
15	Q_M-Conv	Q_H-Conv	Q_M-Mob	Q_H-Mob	Q_M-No	Q_H-No
16	Q_M-Conv	Q_H-Conv	Q_M-No	Q_H-No	Q_M-Mob	Q_H-Mob

17	Q_M-Mob	Q_H-Mob	Q_M-Conv	Q_H-Conv	Q_M-No	Q_H-No
18	Q_M-Mob	Q_H-Mob	Q_M-No	Q_H-No	Q_M-Conv	Q_H-Conv
19	Q_H-No	Q_M-No	Q_H-Mob	Q_M-Mob	Q_H-Conv	Q_M-Conv
20	Q_H-No	Q_M-No	Q_H-Conv	Q_M-Conv	Q_H-Mob	Q_M-Mob
21	Q_H-Conv	Q_M-Conv	Q_H-Mob	Q_M-Mob	Q_H-No	Q_M-No
22	Q_H-Conv	Q_M-Conv	Q_H-No	Q_M-No	Q_H-Mob	Q_M-Mob
23	Q_H-Mob	Q_M-Mob	Q_H-Conv	Q_M-Conv	Q_H-No	Q_M-No
24	Q_H-Mob	Q_M-Mob	Q_H-No	Q_M-No	Q_H-Conv	Q_M-Conv

4.2.8 Scenarios programming

The above scenarios were **programmed** by means of the R8103 Programming Tool software version 3.4 of the driving simulator, in a scripting language supported by the simulator environment. An extract of the source code for one indicative scenario is provided in Annex.

4.3 Procedure of experiment

The **procedure** of the driving simulator experiment constitutes another essential component of the PhD thesis considering that it is based on limitations of similar driving simulators that were reviewed.

This section is **structured** as follows. First, the organisation of the research team is provided and the oral instructions to the participants are presented. Next, special emphasis is given to the familiarisation part as specific performance measures are used to assess the driver's familiarization with the simulator before proceeding to the main part of the experiment. Finally, the process of the main driving scenarios is described

4.3.1 Organization of the research team

The research team of the experiment consists of:

- One researcher – **coordinator** of the experiment:
  The role of the coordinator is to welcome and guide the participants to the room of the driving simulator, at the specified date and time. The researcher is responsible for:
  - the oral briefing and the delivery of the instructions to the participant,
  - assisting the participant during their familiarization drive,

- assisting the participant to fill in the Self-assessment and Memory questionnaire,
- filling a checklist (see Annex) for the control of the experiment with any comments related to anything remarkable regarding the driving of the participant,
- the monitoring for and handling of simulator sickness,
- the accomplishment of the driving simulator experiment,
- assisting the participant in any other issue.

- One (1) researcher responsible for the **distraction tasks and the statistical editing of the data output:**

  The role of this researcher is:
  - performing the distraction tasks during the experiment: the conversation task and the phone call with the participant,
  - assisting for any other secondary issues during the experiment,
  - organizing the files generated from the participants' driving and editing statistically the data.

4.3.2 Oral briefing – instructions

The first action of the coordinator of the experiment is to **brief** the driver orally and in writing (see Annex) regarding the full procedure of the experiment (completion of the questionnaire, total duration, driving preparation etc.). Emphasis is given to the participants in the maintenance of heir usual driving behaviour without being affected from any other factors (stress, fear, etc.).

4.3.3 Familiarization with the simulator

A **familiarization session** or "practice drive" is typically the first step of all simulator experiments. At this point, the coordinator assists participants to sit comfortably on the driving simulator, explains any questions and confirms that participants feel well.

The driving simulator provides a **"Free Driving"** scenario (Figure 4.9) that familiarizes the participants with the demands of an everyday drive. The greater part of the drive is designed in an inter-urban environment, but there is also a short crossing through a small city with traffic lights and junctions.

During the familiarization with the simulator, the participant practiced in (see also Annex):

- handling the simulator (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

Finally during this practice drive, two unexpected incidents take place.

The following criteria must be verified (**there is no time restriction**) before the participant moves on to the next phase of the experiment:

Firstly, the participants drove on straight road **as many times as needed** to feel comfortable with their lane positioning. Then, they drove within the lane at their own comfortable speed. The participants were requested to stay within the lane without touching or crossing the lane boundary for 30 seconds. Secondly, the participants drove on a curvy road. They had to drive without touching or crossing the lane boundaries for sixty seconds. The participants should complete this task as many times as necessary to meet the criteria. The participants completed the task a second time by driving at the posted speed limit (70km/h). In the last practice scenario, participants practiced driving in a small city with several stop signs and traffic lights. Participants were practiced in driving with the appropriate speed and in bringing the vehicle to a complete stop at six intersections.

Figure 4.9 Free driving - familiarization with the simulator

4.3.4 Process of driving scenarios

As mentioned before, following the familiarization drive and the necessary short brake, rural and urban areas followed. Within each road type, two traffic scenarios and three distraction conditions were examined in a full factorial within-subject design, as shown in Table 4.2. More specifically, the distraction conditions were: **no distraction, cell-phone conversation and conversation with passenger**. The traffic scenarios were: **Q_M: Moderate traffic conditions** (Figure 4.10) and **Q_H: High traffic conditions** (Figure 4.111). For **rural area** each participant drove approximately 12,6km within about 20min in total. After the end of each trial (when the driver reached a spot with road works obliging the driver to stop the vehicle - Figure 4.12), the screen instantaneously turned black for a few seconds, and restarted at the beginning of the route for the next trial. When the participant drove all six routes (2,1km each for 3,5min), was having a break.

Figure 4.10 Rural area-moderate traffic volume

As mentioned, each trial was about a different driving distractor and different traffic volume. In addition two unexpected events were set, where the reaction of each driver was recorded.

Figure 4.11 Rural area - high traffic volume

Figure 4.12 End of rural trial

For **urban area** (Figure 4.12) each participant drove approximately 10,2km within about 20min in total. After the end of each trial, the screen instantaneously turned black and restarted at the beginning of the next trial. After the completion of all six routes (1,7km each for 3,5min), the participant had a break.

Figure 4.13 Urban area high traffic volume

In addition two unexpected events are set, where the reaction of each driver is recorded.

4.4 Questionnaires

After completed the driving simulator tasks, participants were asked to fill in **two questionnaires**. The first questionnaire concerned their driving habits and their driving behaviour, while the second was a self-assessment questionnaire that covered aspects related to the driving simulator experience (Vardaki and Karlaftis, 2011). In this section, all the different parts as well as indicative questions of each questionnaire are recorded.

4.4.1 Driving behaviour questionnaire

Each participant was requested to fill in a questionnaire about their **driving habits** and their **driving behaviour**. The questions were chosen carefully on the basis of the existing literature on drivers' self-reported behavior. The sections of the questionnaire were:

- Driving experience - car use
- Self -assessment of the older driver
- Distraction-related driving habits
- Emotions and behaviour of the driver
- Anger expression inventory during driving
- History of accidents, near misses, and traffic violations

The **driving experience** section included questions about the driving experience and driving habits of the participants that were used in analysis as potential moderating factors for the evaluation of driving simulator performance. The section also incorporated questions that examine the driving experience of the participants in different driving environments or situations, e.g., frequency of driving during rush hour, thus providing more detailed information on the driving experience of the participants.

The **self-assessment** of the older driver section included two sub-sections. The questions of the first one required the self-evaluation of the perceptual-motor and the safety skills of the driver. The items of the section were derived from the Driver Skill Inventory (Lajunen & Summala, 1995), with adaptations and modifications by the research team. This section employs a 4-point scale (from weak to strong), in order to prevent the bias of responses that cluster in the middle. The section included an original questionnaire, developed by the research team, which asked the participants to rate their driving skills in relation to their skills of 5 years ago. The rating scale ranged from no difference to significantly worse with respect to driving in different conditions (on a highway, at night, in heavy traffic, etc.). In addition, participants rated whether or not they avoid each one of the conditions included, how often, and if so, whether their avoidance was attributed to their own hesitation, the discouragement of their family, or other reasons. This section offered valuable information on self-awareness of possible driving impairment, as well as possible compensatory mechanisms to avoid safety risks. A questionnaire that inquired about the frequency of various driving difficulties was also included, on a 5-point scale (never-always). The information provided in this section was related to the driving performance of the drivers in the different conditions of the driving simulator experiment.

The **distraction-related driving habits** section included an original questionnaire, developed by the research team, that inquired about the attitudes of the participants with respect to distracting behaviours, e.g., use of cell phone in the city in heavy traffic. The questionnaire employed a 4-point scale (not at all dangerous-very dangerous). The section also included two questions on engaging in distracting behaviors, on a 4-point scale (never-many times), and questions on the use of behavioral adaptations when engaging in distracting behavior, e.g., slowing down and driving more carefully, on a 5-point scale (never-always). The information provided by this section were specifically related to performance in the distraction conditions of the driving simulator experiment.

The **anger expression** inventory section measured different aspects of the emotions and behaviours of the drivers. It included questions on the frequency of engaging in quarrels (0-9+ times a year); questions on safety behaviours, e.g., driving under the influence of alcohol, on a 4-point scale (not at all-very frequently); and a driving anger scale, adapted and modified by the research team from the Driving Anger Expression Inventory (Deffenbacher et al., 1994), rated on a 4-point scale (almost never-almost always). The results of this section were related to performance in those conditions of the driving simulator more likely to result in impatience or anger, e.g., driving in heavy traffic.

Moreover, the results of the section enter further analyses in order to construct an instrument that may be utilized in future research on driver behavior.

The **history of accidents**, near-misses and traffic violations section aimed to elicit specific information on the above, measured in terms of frequency of occurrence (0-9+ times in total, or in the past 2 years, depending on the section).

4.4.2 Self-Assessment and memory questionnaire

After the first two driving sessions, each participant was requested to fill in a **self-assessment questionnaire** that covered aspects related to the driving simulator experience. Indicative sample items are:

- "According to your opinion and in relation to people with your characteristics (level of eduvation and age), your speed in the driving simulator was: i) slow, ii) average, iii) fast"
- "According to your opinion and in relation to people with your characteristics (level of eduvation and age), the distances that you kept from the other cars were: i) small, ii) average, iii) large
- "according to your opinion and in relation to people with your characteristics (level of eduvation and age), your reactions to the various events that occurred were: i) slow, ii) average, iii) fast".

The scope of the various questions that make up the specific questionnaire is to provide information about participants' perception regarding their **driving skills** and more generally regarding the overall driving experience in the simulator.

Also, the participants were administered an **incidental memory questionnaire** (IMQ), developed by the research group, that included questions about the routes they just drove within the driving simulator. Eight items of the IMQ were following the free-recall format and 8 items were following the recognition format. Free recall sample items are:
"What was the color of the ball that crossed the road?"
"What was the speed limit for driving in the town?"

The recognition items that follow the free-recall items covered the same topics as the free-recall items, but this time the participant was instructed to select the correct option among three alternatives. For example, regarding the question about the color of the ball the alternative options were " a) red-orange, b) blue, c) green" and regarding the question about the speed limit in the town the alternatives are "a) 40, b) 50, c) 60". The particular questionnaire that explored the function of memory under non effortful learning conditions aimed to provide complementary information about the association between aspects of memory and the function of driving, since the neuropsychological assessment included instruments that measure memory under effortful learning conditions.

4.5 Data processing

In this section, considering that the dataset from the driving simulator experiment is extremely large, information regarding the data processing are provided including data files, data storage and the processing levels.

4.5.1 Data files

The basic Data Files are listed below:

- **Driver Control File**
  One .xls file was stored with basic information for each driver and for every assessment leg aiming to support the execution of the experiments (*DD-DriverControlFile-v4.xls)*

- **Driving Simulator Data Processing Levels (L0, L1, L2, L3, L4)**
  DRV-L0. Traffic Session Original Log Files
  DRV-L1. Driver Original Data Excel Files
  DRV-L2. Driver Processed Data Excel Files
  DRV-L3. All Drivers Processed Data Excel File
  DRV-L4. All Drivers and All Assessments Processed Data Excel File

4.5.2 Data storage

The experiment **data storage** was performed automatically at the end of each experiment. The data was stored in the folder D:\Logfiles in text format (*.txt). The simulator records data at intervals of 33 to 50 milliseconds (ms) which means that each second measured values for each variable up to 30 times. At first, 33 variables were recorded in each session. In Table 4.4 all these 33 variables are presented and explained:

Table 4.4 Driving simulator variables

	Variable	Explanation
1	Time	current real-time in milliseconds since start of the drive.
2	x-pos	x-position of the vehicle in m.
3	y-pos	y-position of the vehicle in m.
4	z-pos	z-position of the vehicle in m.
5	road	road number of the vehicle in [int].
6	richt	direction of the vehicle on the road in [BOOL] (0/1).
7	rdist	distance of the vehicle from the beginning of the drive in m.
8	rspur	track of the vehicle from the middle of the road in m.
9	ralpha	direction of the vehicle compared to the road direction in degrees.
10	Dist	driven course in meters since begin of the drive.
11	Speed	actual speed in km/h.
12	Brk	brake pedal position in percent.
13	Acc	gas pedal position in percent.
14	Clutch	clutch pedal position in percent.
15	Gear	chosen gear (0 = idle, 6 = reverse).
16	RPM	motor revolvation in 1/min.
17	HWay	headway, distance to the ahead driving vehicle in m.
18	DLeft	distance to the left road board in meter.
19	DRight	distance to the right road board in meter.
20	Wheel	steering wheel position in degrees.
21	THead	time to headway, i. e. to collision with the ahead driving vehicle, in
22	TTL	time to line crossing, time until the road border line is exceeded, in
23	TTC	time to collision (all obstacles), in seconds.
24	AccLat	acceleration lateral, in m/s^2
25	AccLon	acceleration longitudinal, in m/s^2
26	EvVis	event-visible-flag/event-indication, 0 = no event, 1 = event.
27	EvDist	event-distance in m.
28	ErrINo	number of the most important driving failure since the last data set
29	ErrlVal	state date belonging to the failure, content varies according to type of
30	Err2No	number of the next driving failure (maybe empty).
31	Err2Val	additional date to failure 2.
32	Err3No	number of a further driving failure (maybe empty).
33	Err3Val	additional date to failure 3.

4.5.3 Processing levels

The processing level includes 5 discrete steps as follows.

- Processing Level “0”. **Area Type Original Log Files**

There are four .txt files per driver (logfile.txt, errorfile.txt).

e.g. DRV-L0-D006-R-log.txt
e.g. DRV-L0-D006-R-err.txt
e.g. DRV-L0-D006-U-log.txt
e.g. DRV-L0-D006-U-err.txt

Each line corresponds to each measurement (30 measurements per second).

- Processing Level “1”. **Driver Original Data Files**

There is one excel file per driver (1 sheet per logfile and 1 per error file for each session).
Sheets:
- urban-data
- rural-data
- urban errors
- rural-errors

e.g. DRV-L1-D006-original.xls

Each line corresponds to each measurement (30 measurements per second)

- Processing Level “2”. **Driver Processed Data Files**

There is one excel file per driver (1 sheet per logfile and 1 per error file for each session) in which **Summary data** per driver is added. All types of incidents are separated from Sheet 1 and another sheet is created including only **the events**.

There is one sheet per logfile (2 sheets per session) and each line corresponds to each measurement (30 measurements per second)

Sheets:
- summary data (including the performance assessment)
- urban-data (without incidents) with summary data at the bottom
- rural-data (without incidents) with summary data at the bottom
- urban errors with summary data at the bottom
- rural-errors with summary data at the bottom
- urban-incidents
- rural-incidents

e.g. DRV-L2-D006-v4.xls

- Processing Level “3”. **All Drivers Processed Data File**

There is one excel file for all drivers. Each line corresponds to each combination of driving sessions and trials:
- summary data
- summary additional data (driving checklists, questionnaires)
- incidents

e.g. DRV-L3-All-e30-v4.xls 1 file

- Processing Level 4. All Drivers Processed Data File

There is one excel file for all drivers. Each line corresponds to each driver (ready for incorporation to the DD-MasterDataFile-v4.xls)
- summary data

e.g. DRV-L4-All-e30-v4.xls 1 file

4.6 Sample characteristics

Within the framework of the present driving simulator experiment 95 participants had, at least, started the driving simulator experiment that was described analytically in the above chapters. In the present section sample characteristics are presented regarding driver parameters (age, gender, education, experience) as well as driving characteristics.

4.6.1 Driver characteristics

In Table 4.4 the distribution of participants per age and gender is presented. It is shown that almost half of the participants are males (47) and half females (48) indicating that the there is a total balance in the sample regarding gender.

Table 4.5 Distribution of participants per age group and gender

Age group	Female		Male		Total	
18-34	9	19%	19	40%	28	**29%**
35-55	19	40%	12	26%	31	**33%**
55+	20	42%	16	34%	36	**38%**
Total	**48**	**100%**	**47**	**100%**	**95**	**100%**

Furthermore, in order to investigate age characteristics, three age groups were created. Out 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 older driver aged

55-75 years old (Figure 4.14). Again, the counterbalancing in the different age groups is almost equal.

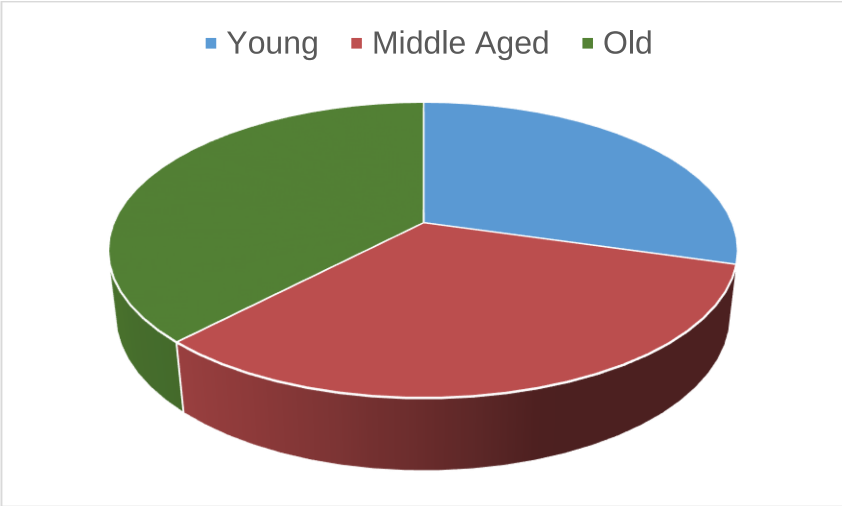

Figure 4.14 Age distribution characteristics

In addition, the average years of education were 15,5 for the whole sample while the average years of driving 25,45 indicating that the majority of participants were experienced drivers. Both statements are presented in the next figure per age group.

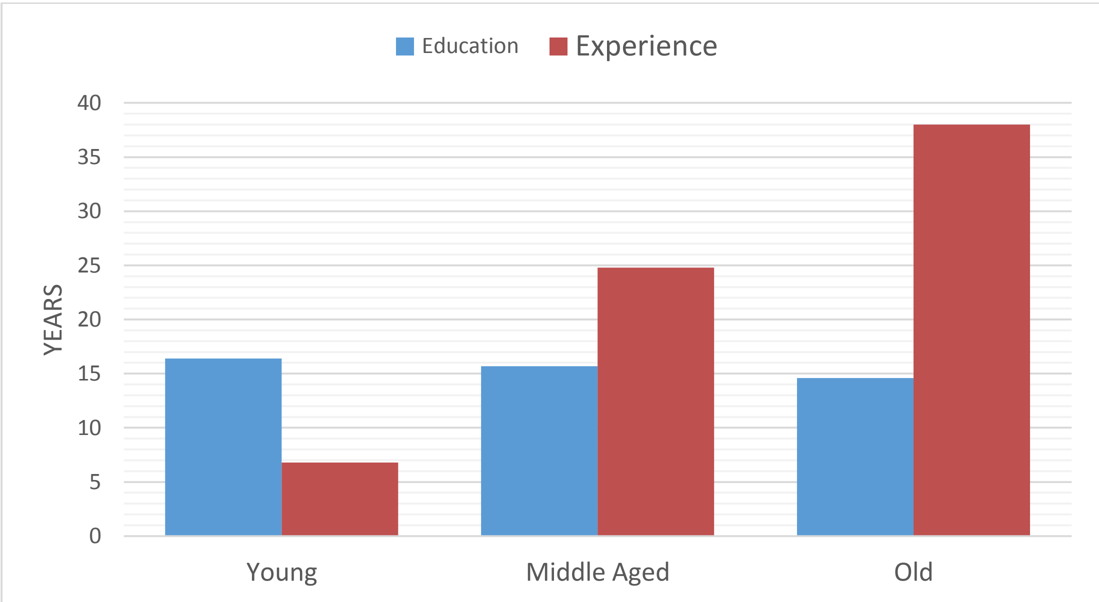

Figure 4.15 Distribution of driving experience and education

4.6.2 Driving characteristics

Since each participants aimed to complete 12 different driving trials, the **total number of trials** were 1.140. However, several participants gave up from the experiment without finishing all the driving trials. As a result, the total number of driving trials completed is reduced to 837.

In Figure 4.16 the **distribution of driving trials** is presented per area type and order of trials. It is shown that 95 participants started the experiment by driving in the first sessions in rural area. However, only 48 drivers managed to complete all 6 driving trials. The respective number is 41 regarding the 6 trials in urban area.

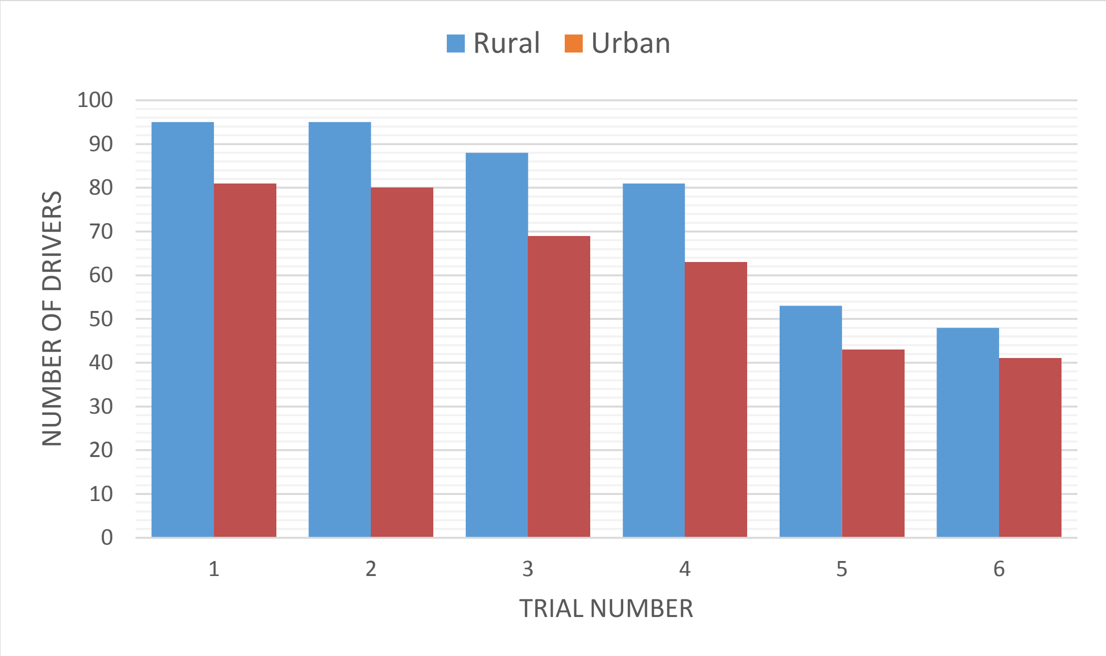

Figure 4.16 Distribution number of driving trials

This is explained by the fact that a significant number of participants came up with **simulator sickness symptoms** during the experiment **and did not manage to complete** all the trials. In addition, the complex driving simulator environment in urban area enhanced these symptoms resulting in fewer number of participants that drove all urban driving scenarios.

As regards the time needed to complete the driving trials, the average time was 3,21 seconds in rural road and 3,19 seconds in urban road. Both results reinforce the design of the experiment which aimed to achieve different road area scenarios in similar time distance.

5. Model development and application

In the present chapter, the data collected from the driving simulator experiment and the respective questionnaires are analysed by means of **a dedicated statistical analysis method**. The choice of this method is based on the limitations and needs of statistical analysis methods, which were analysed in the literature review part on driver distraction experiments. The overall statistical analysis method consists of four steps.

In the first step, the **descriptive analysis** of all the experiment variables takes place, which allows for a first understanding of the large number of parameters examined. More precisely, an overview of all variables that are provided by the driving simulator is provided. Then, several boxplots are presented investigating the effect of specific driving characteristics such as age, gender, area and traffic conditions on different distracted situations on selected driving performance measures. Furthermore, a correlation table is investigating any of a broad class of statistical relationships between driving simulator variables.

Then, in the framework of the explanatory analysis, the development of **regression models** takes place (general linear models and general linear mixed models) regarding key performance parameters such as average speed, reaction time of drivers at unexpected incidents, lateral position, average headway, speed variability, and lateral position variability. Such models are often used in driver distraction analysis in order to estimate the effect of distraction sources and risk factors on specific driving performance parameters and indirectly on driving behaviour and road safety.

In the next step, **factor analysis** is implemented regarding driving performance and driver errors in order to investigate which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the data.

In the fourth step, the core statistical analysis of the present PhD thesis takes place, including the implementation of structural equation models for the first time in the scientific field of driver distraction. Within the framework of **latent analysis**, four Structural Equation Models are developed aiming to investigate the quantification of the impact of driver distraction, driver characteristics as well as road and traffic environment directly on driving performance, driver errors and accident probability.

The four individual steps of the overall statistical method are presented in figure 5.1. It should be noted that both regression and factor analyses are parts of the explanatory analysis of the database and are critical for the development and application of the structural equation models.

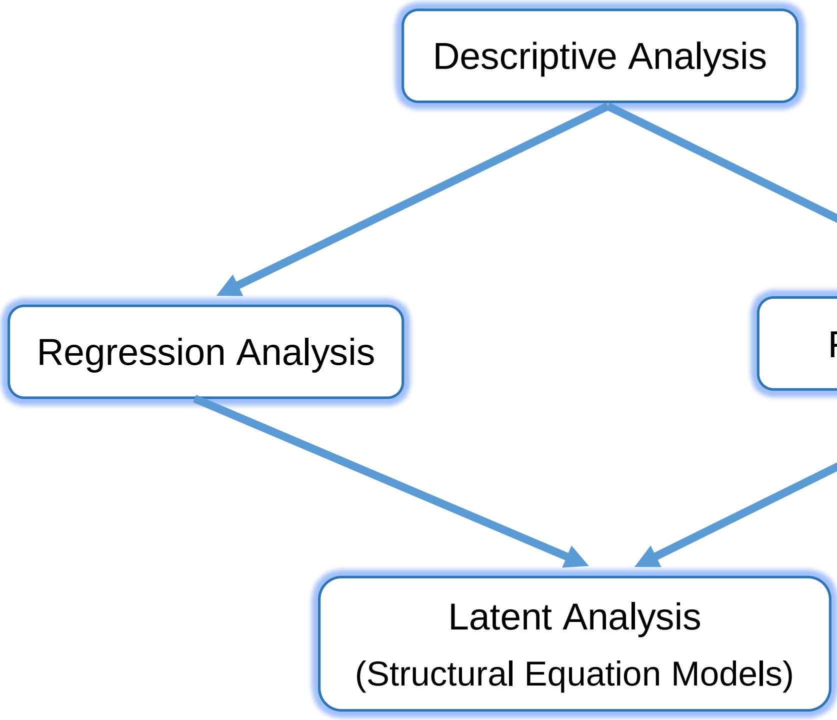

Figure 5.1 PhD Statistical Analyses Steps

5.1 Descriptive analysis

In the present research the large dataset exported from the driving simulator experiment as well as the driving behaviour and self-assessment questionnaires make the descriptive analysis of a large number of variables essential.

In the beginning, characteristics of the final database variables such as the type of variable, minimum, maximum, and average value are provided. Then, several boxplots are presented in order to explain the effect of specific driver, road and traffic parameters as well as the examined distraction sources on selected driving performance measures. Finally, a correlation table is investigating any of a broad class of statistical relationships between driving simulator variables.

With regard to the interpretation of boxplots, it should be noted that the spacing between the different parts of the box plot indicates the degree of dispersion (spread) and skewness in the data and identifies outliers. More specifically:

- The line in the middle of the boxes is the median
- The bottom of the box indicates the 25th percentile. Twenty-five percent of cases have values below the 25th percentile.
- The top of the box represents the 75th percentile. Twenty-five percent of cases have values above the 75th percentile.
- Half of the cases lie within the box.

5.1.1 Database development

The final dataset consists of several types of variables that are categorised as follows:

- Driver characteristics
- Driver error variables
- Driving performance variables

In tables 5.1-5.3, the type of each variable, the minimum, maximum, and average value are presented aiming to give a clear picture of the overall database.

Table 5.1 Driver variables characteristics

Variable	Type	Min	Max	Average
Age	Integer	22,00	78,00	44,47
Education	Integer	0,00	16,00	12,00
Experience	Integer	3,00	50,00	23,06
Gender	nominal	2 levels "F","M":		

Table 5.2 Driver error variables characteristics

Variable	Type	Min	Max	Average
Engine Stops	Integer	0,00	11,00	1,05
Hit Of Side Bars	Integer	0,00	8,00	0,39
Outside Road Lines	Integer	0,00	2,00	0,01
Sudden Brakes	Integer	0,00	9,00	2,32
Speed Limit Violation	Integer	0,00	6,00	0,19
Slow Rounds Per Minute	Integer	0,00	4,00	0,11
High Rounds Per Minute	Integer	0,00	13,00	0,34
Accident	Integer	0,00	2,00	0,14

Table 5.3 Driving performance variables characteristics

Variable	Type	Min	Max	Average
Time run	Numeric	19,00	374,00	129,20
Distance car	Numeric	99,67	3.104,35	1.176,48
Average speed	Numeric	19,63	69,83	39,24
Stdev average speed	Numeric	5,09	30,26	12,67
Reaction time	Numeric	500,00	5.484,00	1.493,00
Lateral position	Numeric	1,16	4,49	2,20
Std lateral position	Numeric	0,15	2,65	0,85
Average direction	Numeric	0,01	4,03	1,93
Std average direction	Numeric	0,00	3,13	1,93
Average brake	Numeric	0,00	7,07	1,87
Std average brake	Numeric	0,00	25,06	12,01
Average gear	Numeric	1,31	4,27	2,75
Std average gear	Numeric	0,34	1,93	1,01
Average motor revolvation	Numeric	1.209,00	5.622,00	2.476,00
Std average motor revolvation	Numeric	273,70	1.795,10	676,70
Average space headway	Numeric	18,76	927,52	206,03
Std average headway	Numeric	13,35	434,22	97,60
Average timeheadway	Numeric	3,54	256,84	37,10
Std Average timeheadway	Numeric	6,61	1.169,97	198,70
Average time to line crossing	Numeric	17,69	552,93	130,72
Std Average time to line crossing	Numeric	113,50	1.492,50	553,20
Average time to collision	Numeric	5,20	22,08	10,10
Std Average time to collision	Numeric	1,54	10,80	5,40

5.1.2 Age and gender distributions

In this section, the effect of driver characteristics is examined on specific driving performance parameters. Particularly, the next figures present the effect of age and gender on average speed and reaction time at unexpected incidents for different types of distraction (undistracted driving, conversing with the passenger and talking on the cell phone).

Figure 5.2 presents the average speed of drivers per distraction factor (no distraction, conversation with passenger, cell phone use), age group (young, middle aged, older), and gender.

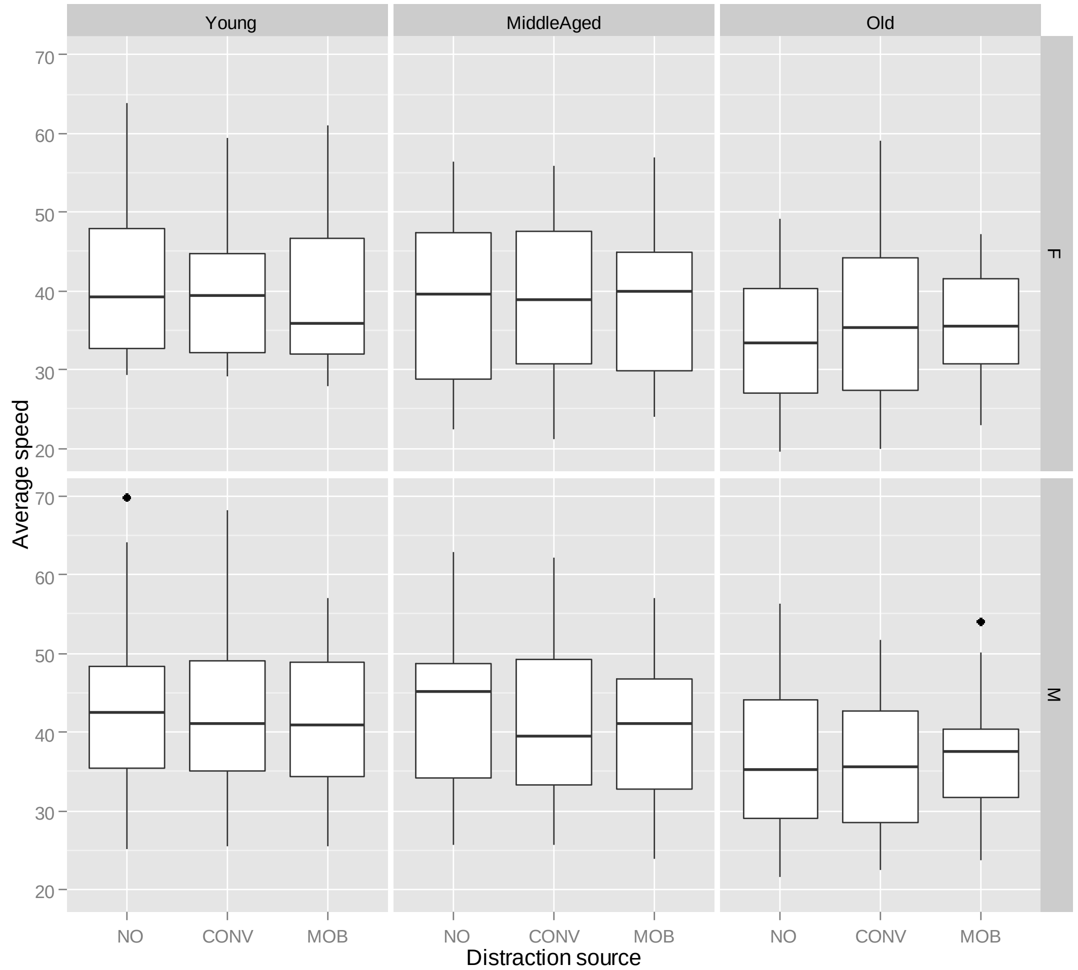

Figure 5.2 Average speed per distraction factor, age group and gender

It is observed that while conversing with the passenger, drivers do not significantly change their average speed. On the other hand, talking on the cell phone, decreases the average speed as part of the compensatory distracted behaviour, especially for young and middle aged drivers.

Regarding the effect of driver characteristics on average speed, male drivers of all age groups drive at higher speeds than female ones. Moreover, an interesting result is that, while being distracted (either conversing with the passenger or talking on the cell phone) older drivers tend to increase their speed, probably due to a feeling of security that exists due to the passenger.

Furthermore, Figure 5.3 shows the reaction time of drivers per distraction factor (no distraction, conversation with passenger cell phone use), age group (young, middle aged, older), and gender.

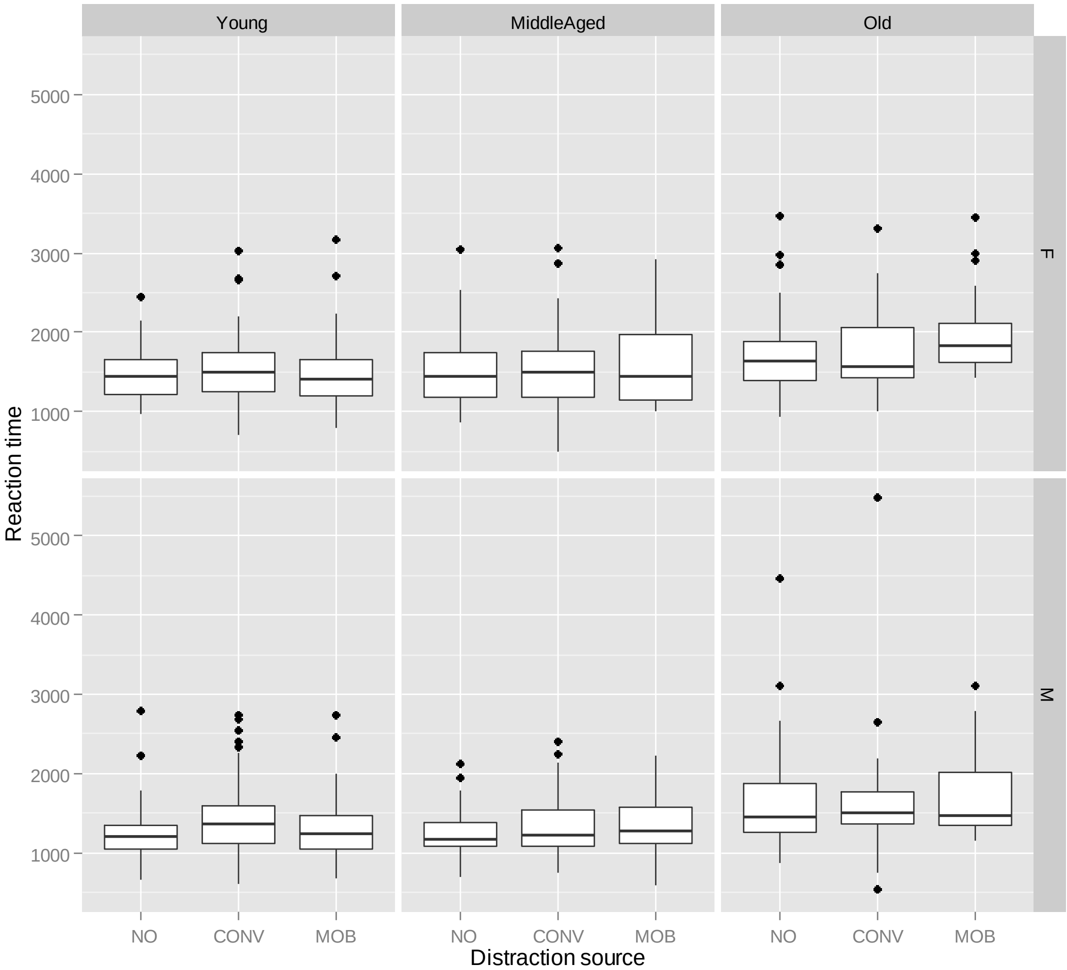

Figure 5.3 Reaction time per distraction factor, age group and gender

It is clearly observed that while talking on the cell phone or conversing with a passenger, drivers of all age groups have higher reaction times compared to undistracted drivers. Furthermore, young and middle aged drivers of both genders are characterized by higher reaction times when conversing with a passenger than when talking on the cell phone.

On the other hand, older drivers have the worst reaction time when talking on the cell phone. Results underline the different distraction mechanism regarding conversing with a passenger and talking on the cell phone that has a direct effect on speed selection and reaction time for different age groups.

<u>5.1.3 Area type and traffic condition distributions</u>

In this section the effect of road and traffic environment on specific driving performance variables is graphically presented. More specifically, the figures presented next show the effect of area type and traffic condition on average speed and reaction time of drivers at unexpected incidents for different types of distraction (undistracted driving, conversing with the passenger and talking on the cell phone).

Figure 5.4 presents the average speed of drivers per distraction factor (no distraction, conversation with passenger cell phone use), area type (urban, rural area) and traffic condition (low/high traffic).

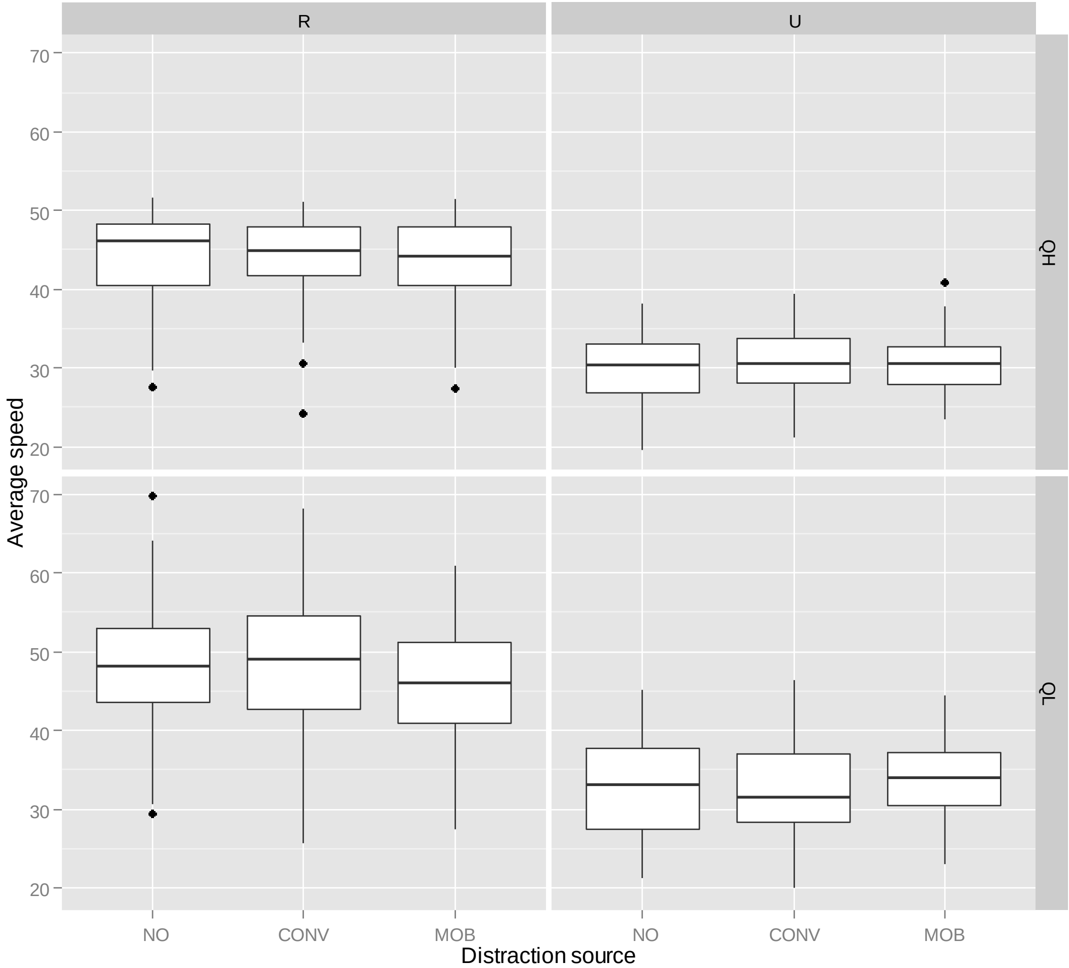

Figure 5.4 Average speed per distraction factor, area type and traffic condition

Boxplots in Figure 5.4 illustrate that average speed is, as expected, lower in urban areas than in rural areas both in high and low traffic. Furthermore, in high traffic the effect of distraction on average speed is less significant. On the other hand, in low traffic conditions in rural areas, talking on the cell phone leads to reductions in average speed in the framework of the compensatory behaviour of the driver.

Figure 5.5 shows the reaction time of drivers per distraction factor (no distraction, conversation with passenger cell phone use), area type (urban, rural area) and traffic condition (low/high traffic).

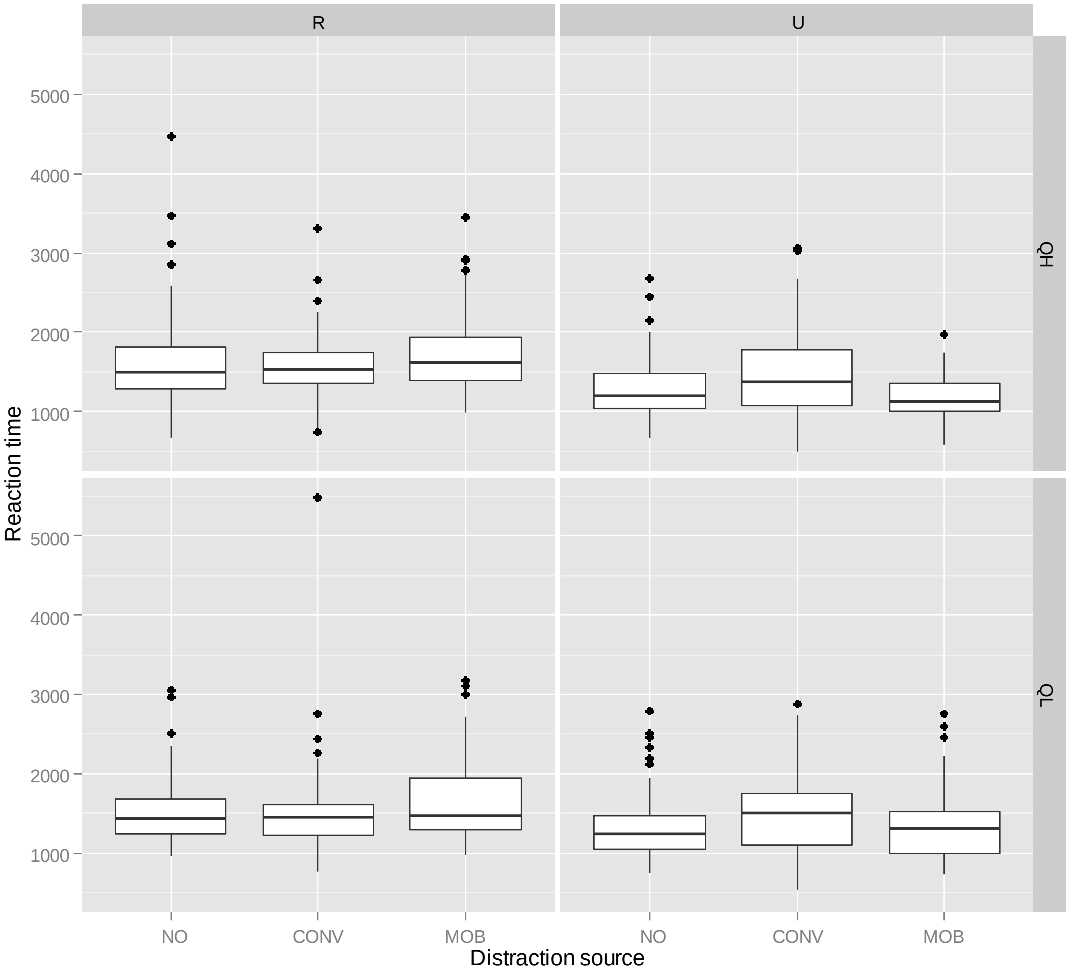

Figure 5.5 Reaction time per distraction factor, area type and traffic condition

Figure 5.5 indicates that both in rural and urban areas in low traffic conditions distracted driving results to increased reaction time. Inside urban area, driver reaction time while conversing with the passenger is clearly higher than talking on the cell phone. This indicates that the often lack of vision on the road of drivers when conversing with the passenger is very dangerous in a complex environment of urban areas.

5.1.4 Correlation table

Before proceeding to the main statistical analysis steps, a correlation table is developed in order 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 5.4 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 two variables. Positive correlation indicates that both variables increase or decrease together, whereas negative correlation indicates that as one variable increases, so the other decreases, and vice versa.

Table 5.4 Correlation table

	Speed	Lateral position	Direction	Average brake	Average gear	Motor revolvation	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 revolvation	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	-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

Table 5.4 determines the relationships between 10 continuous driving performance variables. Results indicate that 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 at unexpected incidents has low correlation coefficients with the variables indicating that there is not a strength correlation between these pairs of variables.

It should be noted that a correlation can only indicate the presence or absence of a relationship, not the nature of the relationship. Correlation is not causation. For this purpose several types of analysis are implemented in the next steps in order to deeply investigate the relationship of these driving performance variables.

5.2 Regression analysis

In the present section, linear regression analysis is implemented in order to identify several sets of explanatory variables that covary with specific driving performance measures of the driving simulator dataset.

Linear regression is used to model a linear relationship between a continuous dependent variable and one or more independent variables. Furthermore, the generalized linear model (GLM) is a flexible generalization of ordinary linear regression that allows for inclusion of dependent variables that have error distribution models other than a normal distribution. The GLM generalizes linear regression by allowing the linear model to be related to the response variable via a link function. It also allows the magnitude of the variance of each measurement to be a function of its predicted value.

In this framework, generalised linear models as well as generalised linear mixed models are presented regarding the following driving performance measures:

- **Average speed -** refers to the average speed of the driver along the route, excluding the small sections in which incidents occurred, and excluding junction areas.
- **Reaction time** - refers to the time between the first appearance of the event on the road and the moment the driver starts to brake.
- **Lateral position** - refers to the distance between the simulator vehicle and the right border of the road.
- **Average headway** - refers to the time distance between the front of the simulator vehicle and the front of the vehicle ahead.
- **Speed variability** - refers to the standard deviation of speed.
- **Lateral position variability** - refers to the standard deviation of lateral position.

The structure regarding each individual regression analysis is the following. Starting with the description of the model, both the dependent and independent variables are recorded in order to set the target of each analysis. Then, the parameter estimates are summarized along with the standard errors, t- and p-values. Note that a variable is considered to be statistically significant at a 90% confidence interval, when its t-value is higher than 1.64 and consequently its p-value is lower than 0,100.

Before accepting the results of the model it is important to evaluate their suitability in explaining the data. One way to do this is to visually examine the residuals. If the model is appropriate, the residual errors should be random and normally distributed. In addition, removing one case should not significantly impact the model's suitability. That statistical software R provides four graphical approaches for evaluating the models as follows:

- <u>The residual errors plotted versus their fitted values</u>
  (The residuals should be randomly distributed around the horizontal line representing a residual error of zero (i.e., there should not be a distinct trend in the distribution of points))
- The square root of the standardized residuals as a function of the fitted values
  (There should be no obvious trend)
- Standard Q-Q plot
  (The residuals should fall on the dotted line)

- Each point's leverage
  (A measure of its importance in determining the regression results)

Furthermore, as presented in the description of the driving simulator experiment, the data used in this research involve repeated measured observations from each individual drive, as each driver completes six drives in rural and six drives in urban environment. For this reason, in order to deal with the heterogeneity across individuals, generalized linear mixed models are implemented and presented next for each model.

Then, the likelihood ratio test is taking place in order to examine the goodness-of-fit for each pair of models. The purpose is to prove that the random effect contributes significantly to the fit of the model and therefore, the fit of the generalized linear mixed models outperforms respective generalized linear models.

Finally, model results are analysed and specific conclusions regarding each driving performance measure are extracted.

5.2.1 Average Speed

The relationship between speed and accidents is widely recognised in the road safety community and as such, speed is a commonly used dependent variable in transportation human factors research including driver distraction research.

The first regression model investigates the relationship between the vehicle average speed and several explanatory variables, namely driver characteristics such as age groups and gender, road and traffic characteristics such as area type and traffic condition, as well as the use of cell phone. The model parameter estimates are summarized in table 5.5.

Table 5.5 Parameter estimates of the GLM of average speed

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	44,847	0,40	111,04	< 0,000
Distraction - Cell phone	-1,217	0,43	-2,82	0,005
Age group - Older	-6,150	0,41	-14,99	< 0,000
Gender - Male	2,675	0,37	7,25	< 0,000
Area type - Urban	-14,536	0,37	-39,31	< 0,000
Traffic - Low	3,170	0,37	8,64	< 0,000
Summary statistics				
AIC	5.183,80			
Log-restricted-likelihood	-2.584,90			
Degrees of freedom	837			

Following the evaluation of the suitability of the model, the following graphs are provided (Figure 5.6). In the upper left graph the residuals are randomly distributed around the horizontal line. In the upper right graph there is no obvious trend in the standard deviation of the residuals. In the Q-Q plot, residuals are on the dotted line while the last diagram is a measure of importance in determining the regression results. All graphs indicate the suitability of the model.

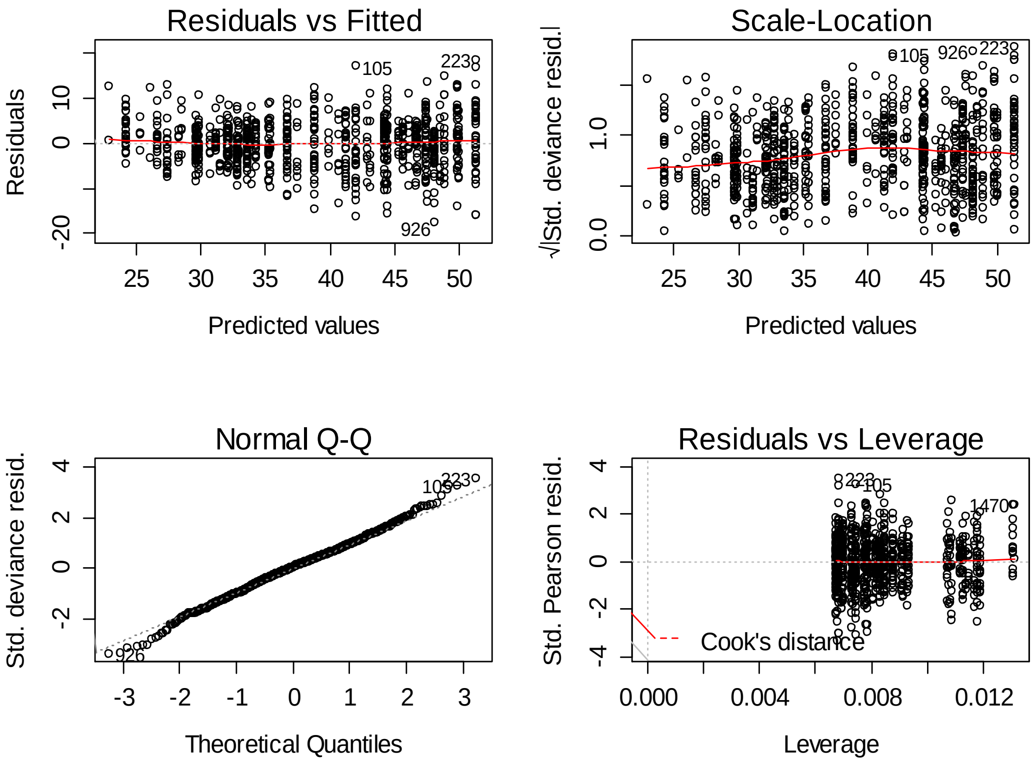

Figure 5.6 Average speed GLM graphical approach of residuals

Since the data involve repeated measured observations from each individual drive, the generalized linear mixed model is implemented and presented in Table 5.6.

Table 5.6 Parameter estimates of the GLMM of average speed

Variables	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	44,847	60,69	60,69	< 0,000
Distraction - Cell phone	-1,217	-6,96	-6,96	< 0,000
Age group - Older	-6,150	-7,32	-7,32	< 0,000
Gender - Male	2,675	2,68	2,68	0,009
Area type - Urban	-14,536	-56,22	-56,22	< 0,000
Traffic - Low	3,170	11,94	11,94	< 0,000
Random effect				
By Person ID (stdev)	4,075	-		
Summary statistics				
AIC	4.809,87			
Log-restricted-likelihood	-2.396,94			

Finally, the likelihood ratio test is taking place in order to examine the goodness-of-fit of the GLMM model. The likelihood ratio test is $LR_{av.speed}$= -375,92 (1 degree of freedom) indicating that the random effect contributes significantly to the fit of the model. Therefore, the fit of the generalised linear mixed model outperforms the respective fit of the generalized linear model.

The final generalised linear mixed model results indicate that several parameters have a statistically significant impact on the average speed of drivers during the driving simulator experiment.

Regarding the distraction sources examined, the use of cell phone while driving results in reduced speeds for all drivers. On the other hand, while conversing with the passenger, drivers do not change significantly the average speed. It can be assumed that the reduction in vehicle speed of drivers using their cell phone results in a road safety benefit, given that lower travel speeds are generally correlated with lower accident risk. However, it is also an indication of the drivers' attempt to counter-balance the increased mental workload resulting from the activity in addition to the physical distraction of the handheld mode

Proceeding to road and traffic characteristics, area type has the highest effect on average speed, as drivers in rural areas drive at the highest speeds, as expected due to the less complex driving environment. In addition, in low traffic conditions drivers of all age groups and both genders are able to reach higher average speed as confirmed from the model results.

Concerning driver characteristics, male drivers reach higher average speed compared to female indicating the aggressive driving of male drivers, which is confirmed in the literature. Finally, regarding the effect of different age groups, older drivers decrease significantly their speed while being distracted indicating that they try to compensate their driving performance as they feel more vulnerable compared to young middle aged ones.

5.2.2 Reaction time

The second regression analysis relates the reaction time of drivers at unexpected incidents to several explanatory variables. Since range of reaction time measures can be examined including number of missed events, number of incorrect responses, reaction time and reaction distance, in the present experiment reaction time is measured at specific unexpected incidents.

The explanatory variables include driver characteristics such as age group and gender, road environment characteristics such as area type as well as distraction sources. The model parameter estimates are summarized in Table 5.7.

Table 5.7 Parameter estimates of the GLM of reaction time

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	1.546,15	36,55	42,31	< 0,000
Distraction - Passenger	66,62	37,23	1,79	0,074
Distraction – Cell phone	85,74	41,98	2,04	0,042
Age group - Older	286,3	36,31	7,90	< 0,000
Gender – Male	-181,90	32,53	-5,59	< 0,000
Area type - Urban	-189,01	32,79	-5,76	< 0,000
Summary statistics				
AIC	12.257,00			
Log-restricted-likelihood	-6.121,50			
Degrees of freedom	810			

Following the evaluation of the suitability of the model, the following graphs are provided (Figure 5.7). All graphs indicate the suitability of the model.

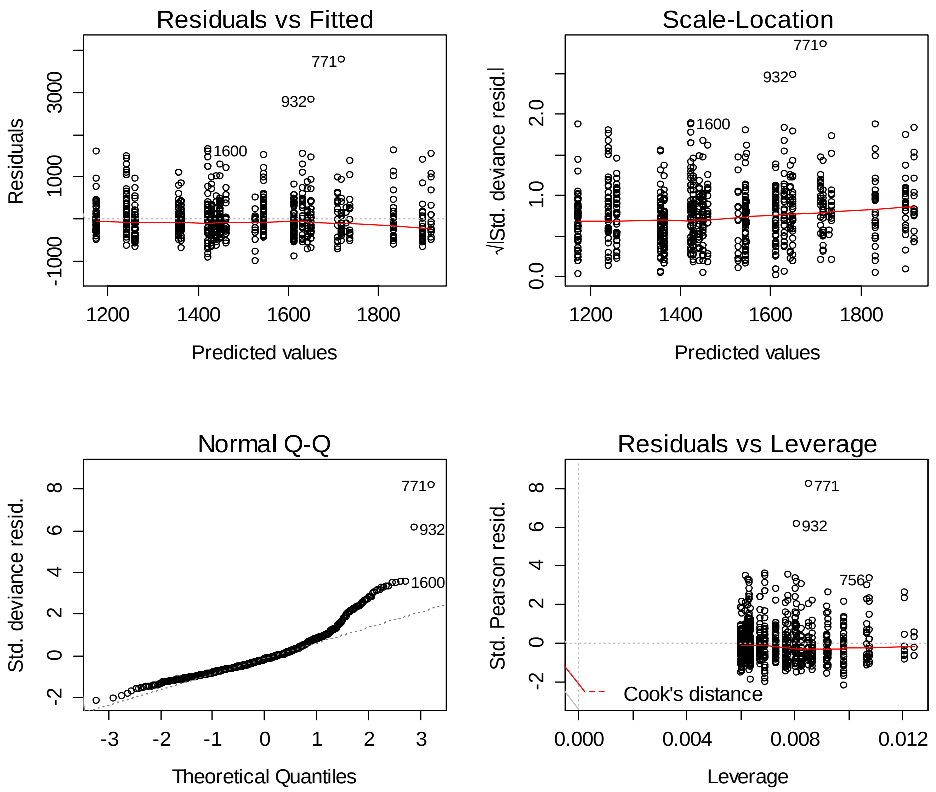

Figure 5.7 Reaction time GLM graphical approach of residuals

Since the data involve repeated measured observations from each individual drive, the generalized linear mixed model is implemented and presented in table 5.8.

Table 5.8 Parameter estimates of the GLMM of reaction time

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	1.544,04	43,85	35,22	< 0,000
Distraction - Passenger	69,82	35,67	1,96	0,051
Distraction – Cell phone	91,84	40,85	2,25	0,025
Age group - Older	292,70	48,50	6,09	< 0,000
Gender – Male	-180,36	45,10	-4,00	< 0,000
Area type - Urban	-188,73	31,57	-5,98	< 0,000
Random effect				
By Person ID (stdev)	153,04	-		
Summary statistics				
AIC	12.189,87			
Log-restricted-likelihood	-6.086,52			

The likelihood ratio test with a value of $LR_{Reaction}$= 69,94 (1 degree of freedom) indicates that the random effect contributes significantly to the fit of the model. As a result, the fit of the generalized linear mixed model outperforms the respective fit of the generalized linear model.

Model results indicate that reaction time of the drivers at unexpected incidents exhibited differences between talking on the cell phone, conversing with the passenger and driving without any distraction. It is observed that, while talking on the cell phone or conversing with passenger, drivers of all age groups have higher reaction times compared with undistracted driving. It is also worth noting that young and middle aged drivers experience higher reaction times when conversing with a passenger than talking on the cell phone.

This is explained by the different distraction mechanism that takes place when talking on the cell phone versus when conversing with a passenger while driving. This difference can be attributed to the driver's age. Cell phone use distraction is consisted of prolonged and repeated glances to the cell phone. Therefore, older drivers have difficulty in maintaining cell devices while driving because they are not as practiced and efficient as technological multi-taskers, commonly younger drivers. On the other hand, when conversing with a passenger, drivers' glance is out of the road very often and this has a more pronounced effect on reaction time of young and middle aged drivers.

Regarding the effect of driver characteristics on reaction time, male drivers achieved much better reaction times compared to female drivers indicating that they are probably more concentrated and perform quicker in case of an unexpected incident. Furthermore, older is the age group with the highest reaction time, as expected.

Finally, in urban areas drivers achieve better reaction time than in rural areas probably due to the fact that in urban areas, the complex road environment keeps the drivers alerted, who in turn self-regulate their driving to compensate for their reduced attention to the driving task.

5.2.3 Lateral position

Lateral position refers to the position of the vehicle on the road in the relation to the right border of the lane in which the vehicle is travelling and it is an indicator on how well the driver maintains the vehicle on the driving simulator environment.

Within this framework, the third regression model investigates the lateral position of the vehicle as a function of driver characteristics such as age group and gender, road environment characteristics such as area type and traffic conditions, as well as the use of cell phone. The model parameter estimates are summarized in table 5.9.

Table 5.9 Parameter estimates of the GLM of Lateral Position

Variables	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	1,49	0,04	37,75	< 0,000
Distraction – Cell phone	0,07	0,04	1,86	0,064
Age group – Middle Aged	0,19	0,04	5,17	< 0,000
Age group - Older	0,19	0,04	4,80	< 0,000
Area type - Urban	1,54	0,03	50,67	< 0,000
Traffic – Low	-0,11	0,03	-3,57	< 0,000
Gender – Male	-0,10	0,03	-3,26	0,001
Summary statistics				
AIC	989,23			
Log-restricted-likelihood	-486,61			
Degrees of freedom	810			

The suitability of the model is investigated through four different graphs as for the previous models, shown in Figure 5.8. All graphs indicate the suitability of the model.

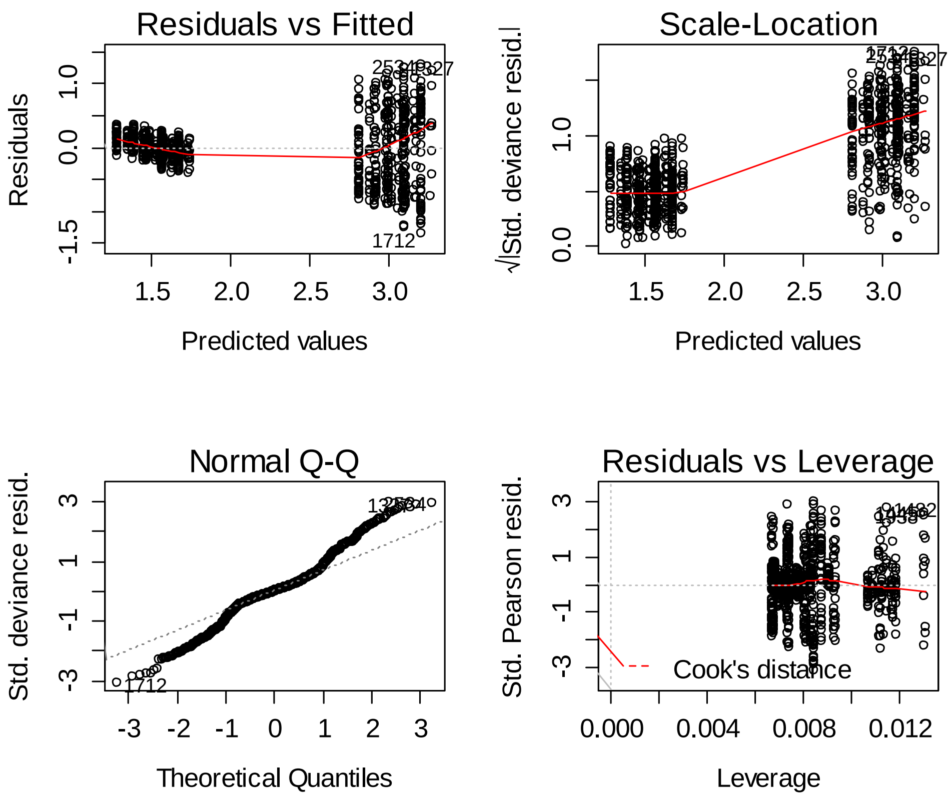

Figure 5.8 Lateral position GLM graphical approach of residuals

Since the data involve repeated measured observations from each individual drive, the generalized linear mixed model is implemented and presented in table 5.10

Table 5.10 Parameter estimates of the GLMM of Lateral Position

Variables	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	1,47	0,06	24,20	< 0,000
Distraction – Cell phone	0,07	0,03	2,30	0,021
Age group – Middle Aged	0,20	0,07	3,11	< 0,000
Age group - Older	0,20	0,06	3,19	< 0,000
Area type - Urban	1,53	0,03	56,71	< 0,000
Traffic – Low	-0,10	0,03	-3,97	< 0,000
Gender – Male	-0,10	0,05	-1,78	0,077
Random effect				
By Person ID (stdev)	0,21	-		
Summary statistics				
AIC	920,51			
Log-restricted-likelihood	-451,26			

The goodness-of-fit is investigated through the likelihood ratio test. The likelihood ratio test regarding lateral position $LR_{lat.pos}$= -70,71 (1 degree of freedom) shows that the random effect contributes significantly to the fit of the model. As a result, the fit of the generalized linear mixed model outperforms the respective fit of the generalized linear model.

The model results indicate that several parameters had a statistically significant effect on the lateral position of the vehicle during the driving simulator experiment.

Regarding the distraction sources examined, cell phone use slightly increased lateral position indicating that drivers find difficult to keep the vehicle in a constant distance from the right board of the lane probably due to the fact that while talking on the cell phone they hold the steering wheel with one hand. On the contrary, conversing with a passenger was not found to affect significantly the lateral position of the vehicle.

With regard to driver characteristics that significantly affect lateral position, male drivers were found to achieve lower lateral position than the female ones confirming the literature that males drive more steadily compared to female drivers. Moreover, two age groups, middle aged and older drivers, have a statistically significant increase on lateral position, proving that they find difficulties in maintaining the driving simulator vehicle compared to young drivers. This is probably explained by the higher physical abilities of young drivers in maintain the steering wheel with only one hand.

Finally, area type has the highest effect on lateral position indicating that lateral position is higher in urban areas, which could be explained by the fact that the urban environment is more complex with much more interactions between vehicles**.**

5.2.4 Average space headway

One of the major contributors to accidents is the headway between two vehicles, when it is too short to allow the following driver to react appropriately to sudden braking by the leading vehicle. The headway between two vehicles can be expressed in terms of time and space.

Within this framework, the fourth regression analysis concerns the average space headway which averages the distance between the following and the leading vehicle measured in meters. The model parameter estimates are summarized in table 5.11.

Table 5.11 Parameter estimates of the GLM of average space headway

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	213,22	7,68	27,78	< 0,000
Distraction – Cell phone	47,22	8,20	5,76	< 0,000
Age group - Older	71,21	7,80	9,13	< 0,000
Gender – Male	-33,30	7,01	-4,75	< 0,000
Traffic – Low	153,07	6,97	21,96	< 0,000
Area type - Urban	-216,45	7,02	-30,79	< 0,000
Summary statistics				
AIC	10.119,00			
Log-restricted-likelihood	-5.052,70			
Degrees of freedom	837			

The suitability of the model is investigated through four different graphs as for the previous models, shown in Figure 5.5. All graphs indicate the suitability of the model.

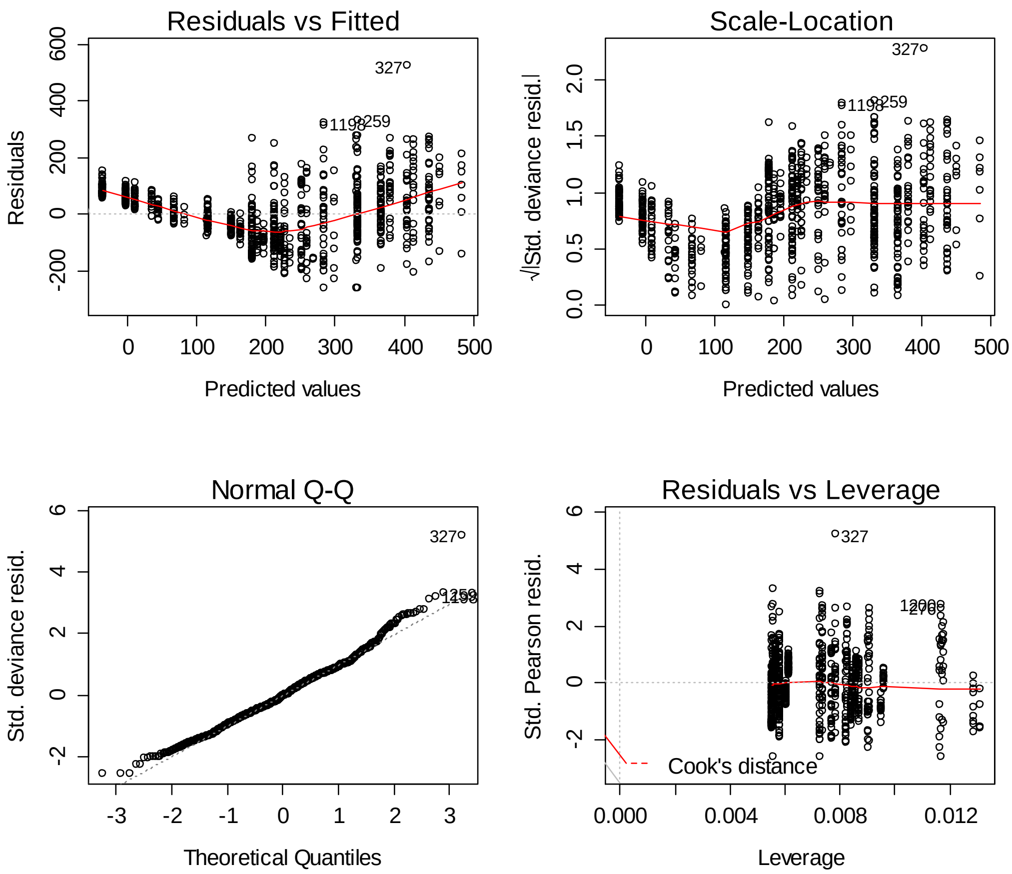

Figure 5.9 Average space headway GLM graphical approach of residuals

The generalized linear mixed model is presented in table 5.12.

Table 5.12 Parameter estimates of the GLMM of average space headway

Variables	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	212,20	10,94	19,40	< 0,000
Distraction – Cell phone	56,92	7,60	7,49	< 0,000
Age group - Older	80,42	12,64	6,36	< 0,000
Gender – Male	-33,82	12,21	-2,77	< 0,007
Traffic – Low	154,53	6,24	24,78	< 0,000
Area type - Urban	-211,04	6,39	-33,01	< 0,000
Random effect				
By Person ID (stdev)	49,58	-		
Summary statistics				
AIC	10.013,28			
Log-restricted-likelihood	-4.998,64			

The results of the likelihood ratio with a value of $LR_{headway}$= -122,43 (1 degree of freedom) indicate that the random effect contributes significantly to the fit of the model and therefore the fit of the generalized linear mixed model outperforms respective generalized linear model.

Several parameters are found to have a statistically significant impact on the average space headway. Cell phone use significantly affects the average space headway. This might occur because while talking on the cell phone drivers tend to keep larger distances from the vehicle in front. This could be explained by the drivers' compensatory behaviour while talking on the cell phone which leads to larger average distances in order to counter-balance the increased mental workload resulting from the activity. On the other hand, conversing with a passenger is not found to affect the average space headway.

Regarding driver characteristics, male drivers tend to keep smaller average space headways compared to female drivers, possibly indicating that male drivers drive more aggressively under all types of distraction. Furthermore, the effect of age is important. The generalised statistical model indicates that older drivers tend to keep much higher distance from the vehicle ahead compared to young and middle aged drivers. This might explained by the fact that older drivers feel more vulnerable while being distracted compared to young and middle aged ones and in order to compensate their driving performance and feel safer while driving, they keep much longer distance from the vehicle in front.

Regarding driving environment, as expected, in urban areas drivers tend to keep smaller average space headways compared to rural areas. This is most likely due to the lower speeds, but also to the more complex driving environment of urban areas including more interactions between vehicles. Another interesting finding is that traffic conditions do not significantly affect the average space headway of drivers.

5.2.5 Speed variability

The next model investigates the impact of several explanatory variables including driver characteristics such as age groups and gender, road environment characteristics such as area type and traffic conditions, and the use of cell phone on speed variability. The model parameter statistics are summarized in table 5.13.

Table 5.13 Parameter estimates of the GLM of speed variability

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	12,89	0,22	57,38	< 0,000
Cell phone	-0,46	0,24	-1,92	0,055
Age group - Older	-2,36	0,23	-10,33	< 0,000
Area type - Urban	-0,57	0,21	-2,79	< 0,000
Gender - Male	0,78	0,21	3,81	< 0,000
Traffic - Low	0,83	0,20	4,05	< 0,000
Summary statistics				
AIC	4.200,40			
Log-restricted-likelihood	-2.093,20			
Degrees of freedom	837			

Figure 5.10 presents the four different graphs that allow for investigating the suitability of the model in predicting speed variability. As for the previous models all graphs indicate the suitability of the model.

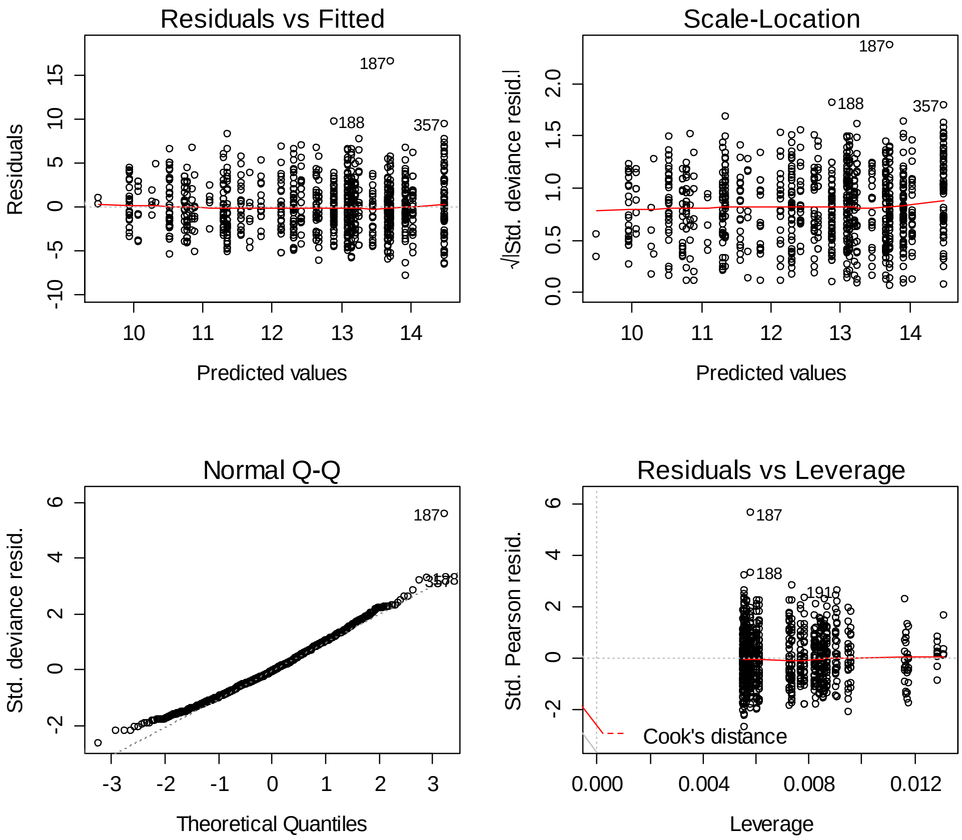

Figure 5.10 Speed variability GLM graphical approach of residuals

The generalized linear mixed model is presented in table 5.14.

Table 5.14 Parameter estimates of the GLMM of speed variability

Variables	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	12,78	0,37	34,09	< 0,000
Cell phone	-0,82	0,19	-4,30	0,055
Age group - Older	-2,11	0,44	-4,81	< 0,000
Area type - Urban	-0,66	0,16	-4,10	< 0,000
Gender - Male	0,75	0,44	1,90	< 0,053
Traffic - Low	0,81	0,16	5,24	< 0,000
Random effect				
By Person ID (stdev)	1,97			
Summary statistics				
AIC	3.932,84			
Log-restricted-likelihood	-1.958,42			

The likelihood ratio test with a value of $LR_{speed.var}$= -269,52 (1 degree of freedom) for the speed variability indicates that the random effect contributes significantly to the fit of the model. Therefore, the generalized linear mixed model outperforms the respective generalized linear model.

Based on the generalised linear mixed model presented above several parameters significantly affected the standard deviation of speed during the driving simulator experiment.

Cell phone use is found to decrease speed variability. This is another outcome of the compensatory behaviour of drivers who tend to drive in lower speeds and with decreased speed variability when talking on the cell phone in order to counterbalance the increased mental and physical weight of the distraction activity. On the other hand, it is not surprising the fact that conversing with a passenger is not found to affect the speed variability since it does not affect significantly the average speed of drivers.

Regarding gender, male drivers within the framework of the aggressive driving were found to have higher speed variability compared to female drivers. Moreover, the highest effect on the standard deviation of speed is occurring on the age group of older drivers as it was found that older drivers tend to have much lower speed variability compared to young and middle aged ones. This is probably explained by the fact that older drivers achieve much lower average speed under all types of distraction and as a consequence they drive more steadily compared to the other age groups.

Finally, regarding the driving environment, speed variability is higher in rural areas and in high traffic. In both conditions, drivers achieve higher average speeds under all types of distraction which explains the result of higher speed variability.

5.2.6 Lateral position variability

Lateral position variability is another critical lateral measure which indicates how well drivers maintain vehicle position within a lane and it is estimated as the standard deviation of the lateral position of each driver.

Within this framework, the present regression analysis is exploring lateral position variability while explanatory variables include driver characteristics such as age groups and gender, road environment characteristics such as area type as well as the use of cell phones. The model parameter statistics are summarized in table 5.15.

Table 5.15 Parameter estimates of the GLM of lateral position variability

Variables	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	3,77	0,6	64,63	< 0,000
Distraction - Cell phone	-0,06	0,02	-2,44	0,015
Age group - Middle Aged	-0,09	0,02	-,81	< 0,000
Age group - Older	-0,08	0,03	-2,83	< 0,000
Area type - Urban	-3,12	0,06	-56,09	< 0,000
Gender - Male	0,11	0,02	5,44	< 0,000
Summary statistics				
AIC	-377,06			
Log-restricted-likelihood	195,53			
Degrees of freedom	837			

Figure 5.11 presents the four different graphs that allow for investigating the suitability of the model in predicting lateral position variability. As for the previous models all graphs indicate the suitability of the model.

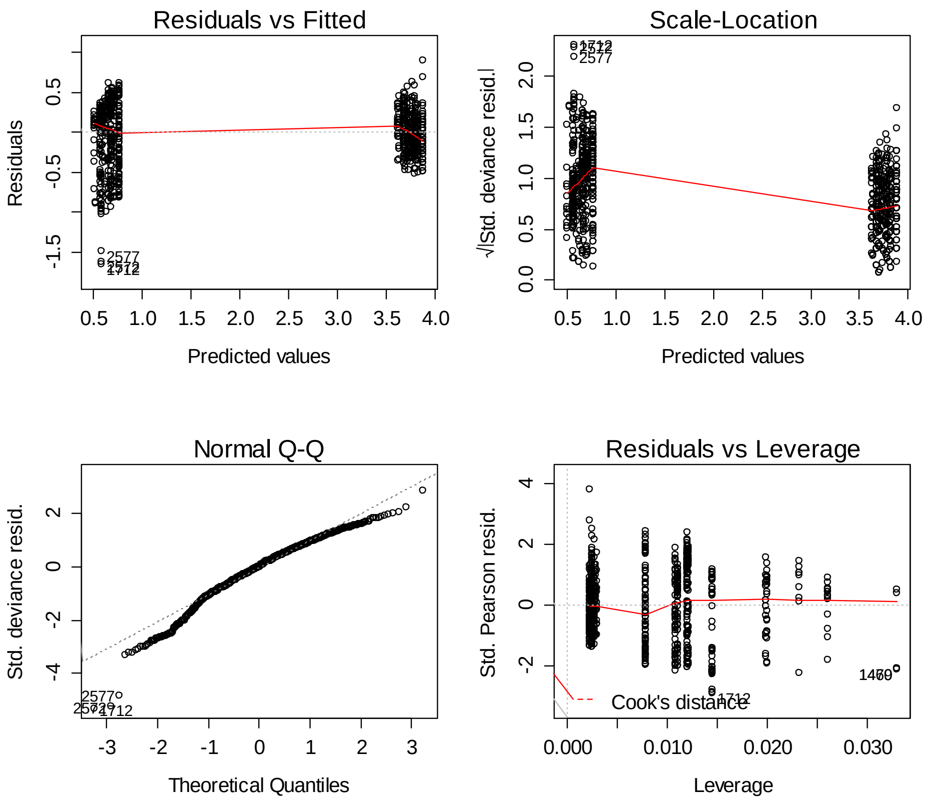

Figure 5.11 Lateral position variability GLM graphical approach of residuals

The parameter estimates of the generalized linear mixed model are presented in table 5.16.

Table 5.16 Parameter estimates of the GLMM of lateral position variability

Variables	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0,23	0,05	4,41	< 0,000
Distraction - Cell phone	0,07	0,03	2,30	0,022
Age group - Middle Aged	0,13	0,06	2,25	0,027
Age group - Older	0,10	0,06	1,79	0,074
Area type - Urban	1,29	0,03	49,71	< 0,000
Gender - Male	-0,11	0,05	-2,35	< 0,021
Random effect				
By Person ID (stdev)	0,18			
Summary statistics				
AIC	839,16			
Log-restricted-likelihood	-411,58			

The likelihood ratio test with a value of $LR_{L.pos.var}$= -24,20 (1 degree of freedom) indicates that the random effect contributes significantly to the fit of the model and therefore the generalized linear mixed model outperforms the respective generalized linear model.

Several parameters are found to significantly affect the standard deviation of lateral position during the driving simulator experiment as follows.

Regarding the distraction sources examined, cell phone use slightly increased lateral position variability indicating that drivers while talking and holding the cell phone find difficult to maintain the vehicle probably due to the fact that they hold the steering wheel with one hand while the second hand holds the cell phone. On the contrary, conversing with a passenger was not found to affect significantly the lateral position variability of the vehicle which is not surprisingly since it does not affect significantly neither the lateral position of drivers as it was proved in a previews regression model.

Regarding driver characteristics male drivers were found to achieve lower lateral position variability than the female ones indicating that male driver more steadily compared to female drivers, a fact that is confirmed in the literature. Moreover, two age groups, middle aged and older drivers, have a statistically significant increase in lateral position variability, proving that they find difficulties in maintaining the driving simulator vehicle compared to young drivers, probably explained by the higher physical abilities of young drivers to maintain the steering wheel especially with only one hand.

Finally, area has the highest effect on lateral position variability indicating that lateral position variability is higher in urban areas, which could be explained by the fact that the urban environment is more complex with much more interactions between vehicles**.**

5.3 Factor analysis

A distinct part of the analysis is devoted to the estimation of **driving performance** and **driver error** factors using the variables that are recorder from the driving simulator experiments.

In statistics, an **exploratory factor analysis** is used in the early investigation of a set of multivariate data to determine whether the factor analysis model is useful in providing a parsimonious way of describing and accounting for the relationships between the observed variables. For the purpose of this study, this type of analysis will determine which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the data. In an exploratory factor analysis, no constraints are placed on which variables load on which factors.

Furthermore, as described in the database characteristics, the driving simulator dataset consists of different types of variables. In this dissertation, in the third step of the statistical analysis, factor analysis is implemented aiming to estimate the key driving measures that underline driving performance and driver errors.

5.3.1 Driving performance factor analysis

First, a factor analysis is performed to investigate which observed continuous variables from the driving simulator experiment are most correlated with the common factors that underline driving performance. In addition, it allows us to determine how many common factors are needed to obtain an adequate description of the data.

In this dissertation. 17 variables are included in the driving simulator database under consideration. Table 5.17 presents a matrix of loadings for each of the variables. The factors presented in the table indicate how much the variable explains its corresponding factor. It should be noted that small loadings are conventionally not printed (replaced by spaces), to draw attention to the pattern of the larger loadings. Moreover, all variables have been sorted regarding the loadings.

Table 5.17 Driving performance factor analysis loadings

	factor 1	factor 2	factor 3	factor 4	factor 5
Lateral Position	0,81				
Std Lateral Position	0,79				
Brake Average	0,66				
Std Brake Average	0,64				
HWayAverage	-0,83				
StdHWayAverage	-0,80				
TTLAverage	0,71				
Average Speed		0,75			
Stdev Average Speed		0,66			
Gear Average		0,68			
Std Gear Average		0,60			
Ralpha Average			0,97		
Std Ralpha Average			0,98		
Thead Average				0,95	
Std Thead Average				0,89	
Rpm Average					0,93
Std Rpm Average					0,60

Summary statistics	**factor 1**	**factor 2**	**factor 3**	**factor 4**	**factor 5**
ss loadings	4,94	2,18	2,07	2,04	1,74
proportion var	0,29	0,13	0,12	0,12	0,10
cumulative var	0,29	0,42	0,54	0,66	0,76

	factor 1	**factor 2**	**factor 3**	**factor 4**	**factor 5**
Interpretation	lateral	speed	direction	headway	revolvation

Results from the first factor analysis indicate that five factors are best fitted (proportion var=10%) regarding this specific database. These five factors represent 76% of the overall database.

Regarding the first factor, lateral position as well as lateral position variability have the highest loadings amongst all variables. This reveals that the first factor represents lateral control measures which indicates how well drivers maintain their vehicle position.

In the second factor, average speed, average speed variability as well as average gear have the highest loadings indicating that the second factor represents the longitudinal measure of speed.

Loading in the third, fourth, and fifth factor give a clear view of what these factors represent since only two correlated variables in each factor have significant loadings. More specifically, the third factor represents the average direction of the vehicle compared to the road direction. The fourth factor represents the average time headway, and the fifth factor the average motor revolvation.

The present factor analysis investigated which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the driving performance data. In the next step, in order to implement structural equation models on the specific database only one latent variable will be created to estimate the overall driving performance. The present factor analysis will guide the creation of the latent variable in section 5.3.

5.2.2 Driver errors factor analysis

Driving error has long been a focus of road safety research. As a result, a range of methods have been developed to specifically measure this concept, including the Driver Behaviour Questionnaire (Reason, 1990). Estimates suggest that driving error is a causal factor in 75% (Hankey et al., 1999), and even up to 95% (Rumar, 1990) of road accidents and, thus, is a significant contributor to road accident.

The objective of the explanatory factor analysis on driving errors is to estimate which variables obtained from the driving simulator experiments have the bigger estimate on the unobserved driving error variable. For this purpose, a factor analysis was implemented in which seven driving performance variables consisted the respective database. In table 5.18 the loadings of the respective variables are recorded indicating how much each variable explains the factor. It should be noted that small loadings are conventionally not printed (replaced by spaces), since the focus is drawn to the pattern of the larger loadings.

Table 5.18 Driving error factor analysis loadings

Factor	Loading
Hit of Side Bars	**0,54**
Outside Road Lines	**0,44**
High Rounds Per Minute	**0,43**
Sudden Brakes	
Speed Limit Violation	
Engine Stops	
Slow Rounds Per Minute	

Summary statistics	
ss loadings	0,73
proportion var	0,10
cumulative var	0,36

	factor 1
Interpretation	Driver error

The results indicate that the hypothesis test that one factor can underline participant driving errors is sufficient. The specific variables that have the highest loadings in this factor analysis, i.e., the ones that tend to explain better the new 'Driving Error" factor are Outside Road Lines, Sudden Brakes and High Rounds per Minute.

Note that this is the first part of the Structural Equation Models that are implemented in the next section. The creation of a latent variable that underlines the driving errors of participants will be based on this factor analysis.

5.4 Latent analysis (Structural Equation Models)

An exploratory factor analysis as described in section 5.3 is used to determine whether the factor analysis model is useful in providing a parsimonious way of describing and accounting for the relationships between the observed variables. This analysis determined which observed variables are most highly correlated with the common factors and the number of common factors needed to provide an adequate description of the data.

Based on this explanatory factor analysis, this PhD dissertation implements structural equation models (SEMs), which are presented in this section. This is the main statistical analysis contribution of this research since SEMs have never been utilized before in the scientific field of driver distraction.

SEMs allow both response and explanatory latent variables to be linked by a series of linear equations. The aim of structural equation models is used essentially in order to **explain the correlations** or covariances of the observed variables in terms of the relationships these variables have with the assumed underlying latent variables and the relationships postulated between the latent variables themselves.

For the purpose of this research, two latent variables are created, **driving performance** variable, which reflects the underlying driving performance of the participants, and **driver error** variable, which reflects the driver errors of the participants.

Then, four different structural equation models are developed as described graphically in the next figure and explained below:

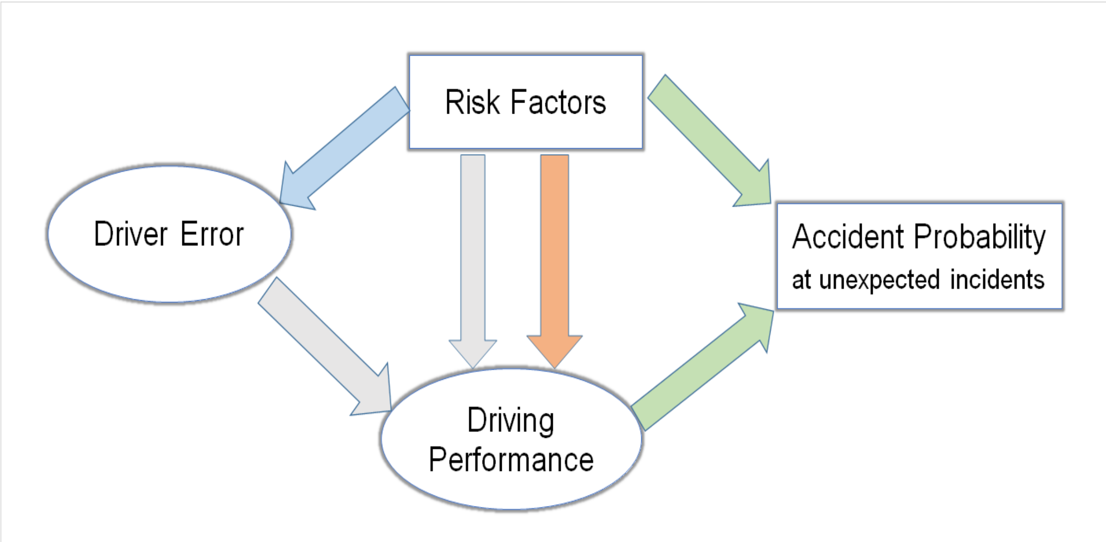

Figure 5.12. Structural Equation Models

- In the first SEM (orange arrow), the latent variable reflects the underlying **driving performance** and the objective is the quantification of the impact of distraction, driver characteristics as well as road and traffic environment on driving performance.
- In the second SEM (blue arrow), the latent variable reflects the underlying **driver error** and the objective is the quantification of the impact distraction, driver characteristics as well as road and traffic environment on driving errors.
- In the third SEM (grey arrow), two latent variables are created regarding **driving performance and driver error** while the objective of this analysis is the quantification of the impact of driving errors, distraction, driver characteristics as well as road and traffic environment on driving performance.
- In the fourth SEM (green arrow), the latent variable reflects again the underlying driving performance of the participants and the objective is the quantification of the impact of driving performance, distraction, driver characteristics as well as road and traffic environment directly on **accident probability an unexpected incidents**.

The **overall aim** of the present analysis is to investigate all the critical risk factors that affect driving performance and driver errors and then to correlate driving performance and risk factors with accident probability. The structure of the presentation for each individual structural equation model is the following.

In the beginning, the **description** of the structural equation model is presented including all the variables in both steps of the model. This is followed by a first graphical approach, which helps to better understand the objective of this specific analysis. Then, a summary table including all parameter estimates is presented. More specifically, in the upper part of the table the variables that create the new latent (unobserved) variable are recorder with the respective parameters (estimate, Standard error, t-statistic, probability). In the lower part of the table, the second phase of the SEM is presented including the regression analysis parameter estimates.

In order to evaluate the overall suitability of the whole SEM four summary goodness-of-fit measures are reported:

- Standardized Root Average Square Residual (SRMR),
- Root Average Square Error of Approximation (RMSEA)
- Comparative Fit Index (CFI).
- Tucker Lewis Index (TLI)

In section 3.2.3.2 all the goodness-of-fit measures are further analysed. It is noted that values of the SRMR range between zero and one, with well-fitting models having values less than 0.08. The appropriate acceptable cut-off point for the RMSEA has been a topic of debate, but in general it lies within 0.06 and 0.08, while 0.07 is often considered as having the general consensus. For the final two goodness of fit measures, the Comparative Fit Index (CFI) and the Tucker Lewis Index (TLI) values larger of 0.90 or even 0.95 are advised.

Then, the path diagram of the model is presented. Path analysis 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.

It is worth mentioning that each latent variable is an unobserved variable that has no established unit of measurement. Therefore, to define the unit of measurement of each latent variable, a non-zero coefficient (usually one) is given to one of its observed variables as an indicator (i.e., reference variable).

Finally, model results are analysed and specific conclusions are extracted regarding each Structural Equation Model.

5.4.1 SEM regarding driving performance

As presented in the methodological chapter, several driving performance measures exist for the evaluation of driving performance, the selection of which should be guided by a number of general rules related to the nature of the task examined as well as the specific research questions. In this section, for the first time, driving performance is defined as a new, unobserved variable, within the framework of latent analysis. Consequently, the effect of distraction, driver as well as road and traffic characteristics are estimated directly on driving performance (instead of being estimated on individual driving performance measures).

More specifically, in this first SEM the latent variable reflects the underlying driving performance of the participants and is based on driving performance variables extracted from the factor analysis of the previous section. In the second part of the SEM, driving performance is the dependent variable while the independent variables include several risk factors such as cell phone use, area type, traffic conditions as well as driver characteristics (age group, gender, driving experience). The graphical structure of the present SEM is presented in figure 5.13.

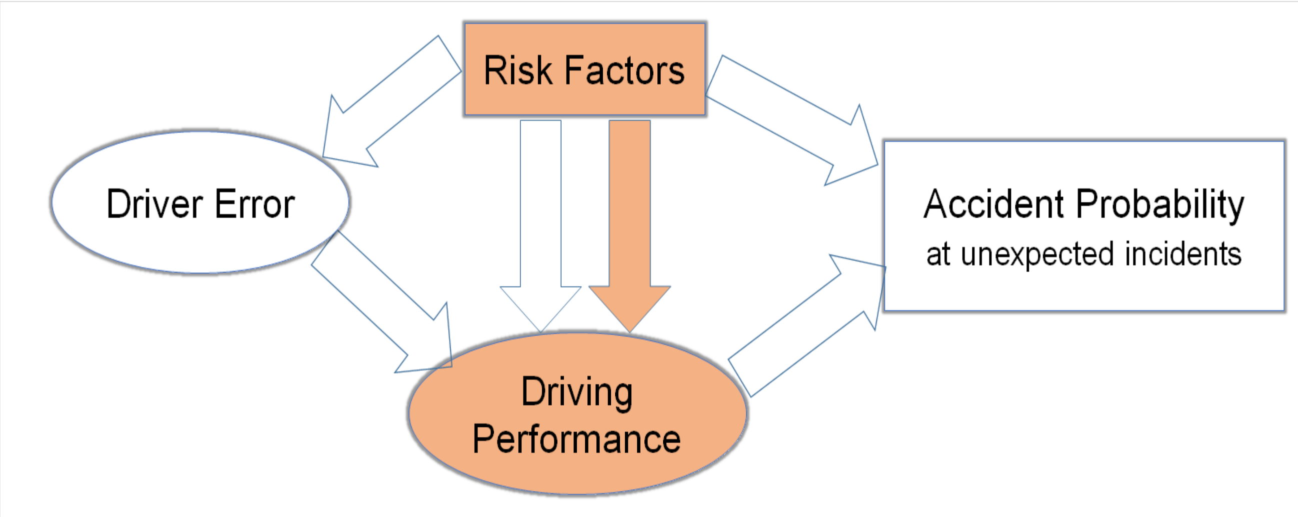

Figure 5.13 Graphical structure of the driving performance SEM

The estimation results are presented in Table 5.19. It is shown that the unobserved (latent) variable which reflects driving performance consists of four variables: average speed, standard deviation of lateral position, average brake, and average time to line crossing.

Table 5.19 Estimation results of the driving performance SEM

	Est.	Std.err	t value.	P(>|z|)
Latent Variable				
Driving Performance				
Average Speed	1,000	-	-	-
Stdev 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				
SRMR	**0,061**			
RMSEA	0,136			
CFI	0,867			
TLI	0,809			

The obtained value of SRMR (0.061) for this model is accepted (<0,08) proving that the overall SEM is suitable. Furthermore, the other three goodness-of-fit measures are close to the respective limits. The respective path diagram is presented in Figure 5.14.

Green lines express a positive correlation while red lines express a negative one. Furthermore, dashed lines indicate which variables create the latent one (first part of the SEM) while continuous lines indicate which variables exist in the regression part of the SEM. Finally the label values represent the standardized parameter estimates.

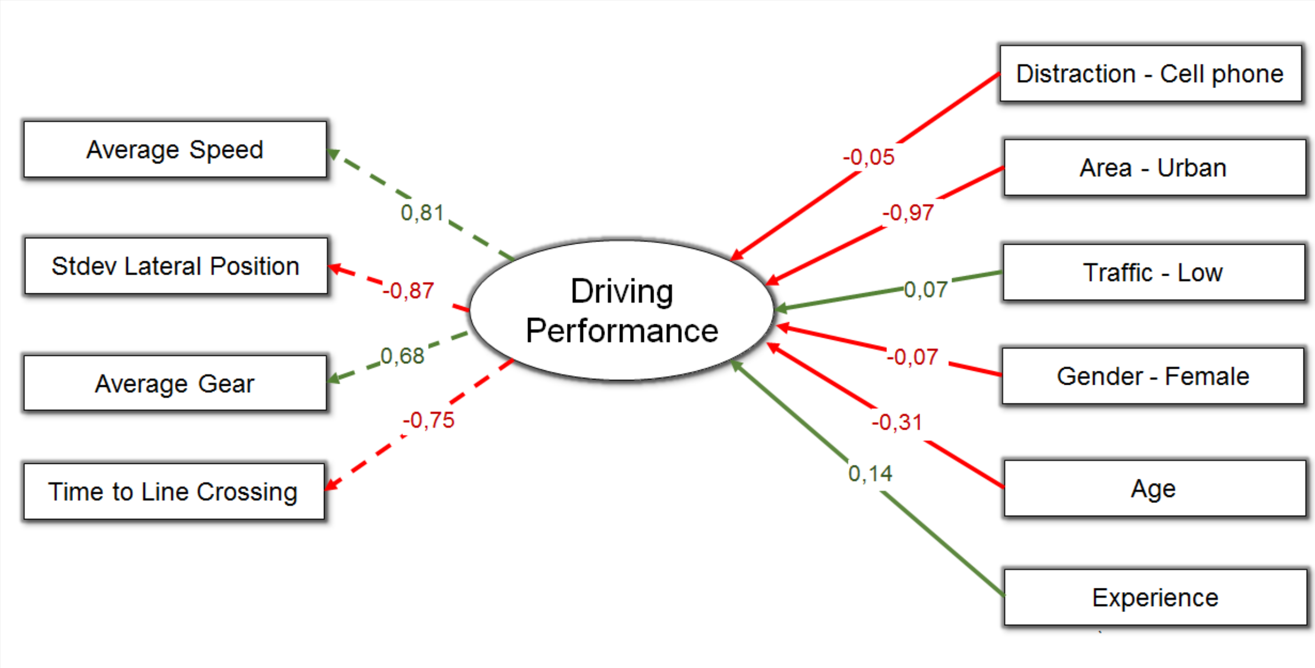

Figure 5.14 Path diagram of the driving performance SEM

In the first part of the model, 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. Note that the selected driving performance measures which create the latent variable have the highest loadings in the respective explanatory factors analysis presented in the previous section.

In the second part of the structural equation model, driving performance is the dependent variable while the independent variables include cell phone use, area type, traffic conditions as well as several driver characteristics.

Regarding the effect of distraction on driving performance, conversation with the passenger was not found to have a statistically significant effect proving 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” shows that the effect of cell phone on driving performance is definitely negative. This change in driving performance might be due to two contradictory reasons. Firstly, due to the the amount of physical and mental resources that required to perform the distraction task. Secondly within the framework of the compensatory behaviour in which drivers change the driving performance in order to counterbalance the distraction activity.

Regarding driver characteristics, both age, gender and experience are statistically significant in the regression part of the model indicating that driver characteristics play the most crucial role in driving performance. More specifically, model results indicate that driving performance is negatively affected for female and age. Regarding gender, this finding confirms the initial hypothesis that female driver are worst performing than male drivers, especially when being distracted. Furthermore, reganding the effect of age, young drivers are better familiarised with the use of cell phone and as a consequence their driving performance is better than middle aged and older driver who find difficulties in maintaining their performance when being distracted. However, this effect is partially counterbalanced by the fact that experience is important in the driving performance as proved by the statistical model above.

Finally, regarding area and traffic characteristics, results indicate that area type is the most significant factor affecting drivers' performance as in urban areas driving performance was negatively affected. This is probably explained by the more complex road environment on urban areas. Traffic conditions also influence driving performance as 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 a lot of interactions between vehicles has a totally negative effect on driving performance.

5.4.2 SEM regarding driver error

Previous research indicate that driver error is a significant contributor to road accidents. Driver error is a causal factor in 75% (Hankey et al., 1999), or even up to 95% (Rumar, 1990) of road accidents. As with driver distraction, there have been numerous attempts to define human error and no one universally accepted definition exists. Furthermore, several parameters exist aiming to investigate driver error. In this section, for the first time, driver error is defined as a new unobserved variable within the framework of latent analysis. Consequently, the effect of distraction, driver as well as road end traffic characteristics is estimated directly on driver error (instead of estimated on individual variables).

More specifically, in this second SEM the latent variable reflects driver error and is based on driving simulator variables extracted from the factor analysis of the previous section. All these variables are discrete and consist of one factor in the respective analysis in section 5.2.2. Furthermore, several other indicators play a role in the driving error and are investigated in the second part of the SEM where drive error is the dependent variable and the independent variables include several driver and road characteristics. The graphical structure of the present SEM is presented in figure 5.15.

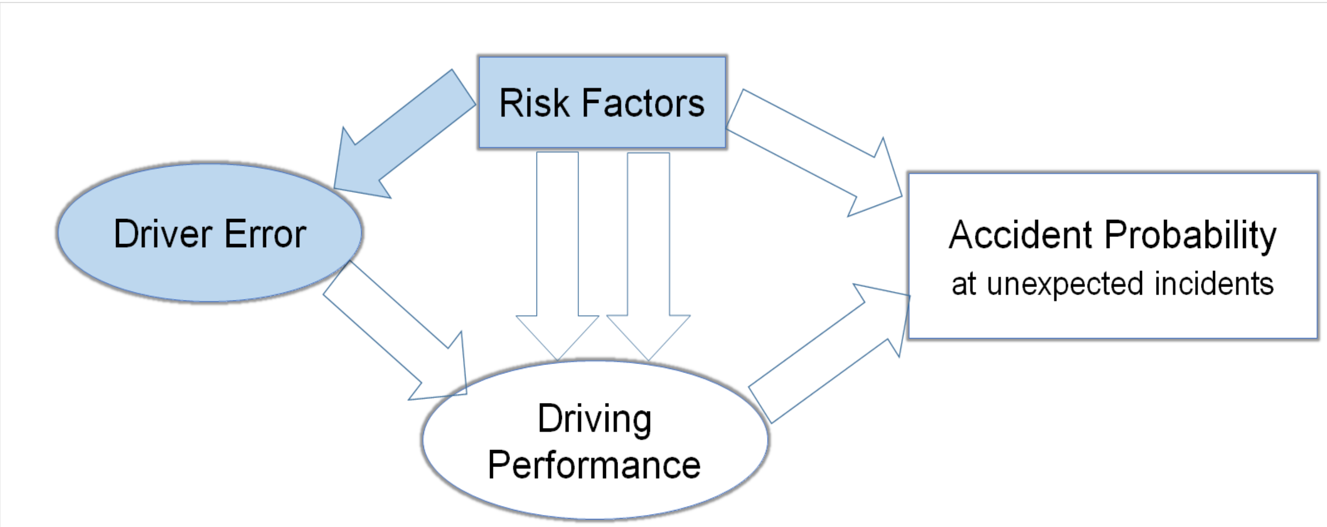

Figure 5.15 Graphical structure of the driver error SEM

The estimation results are presented in Table 5.20. It is shown that the unobserved (latent) variable which reflects driver error consists of three variables: Hit of Side Bars, Outside Road Lanes and High Rounds per Minute.

Table 5.20 Estimation results of the driver error SEM

	Est.	Std.err	t value.	P(>|z|)
Latent Variable				
Driving Error				
Hit Of Side Bars	1,000	-	-	-
Outside Road Lanes	0,741	0,257	2,887	0,004
High Rounds Per Minute	0,680	0,243	2,803	0,005
Regressions				
Driver Errors				
Gender - Female	0,359	0,076	4,739	0.000
Age	0,031	0,009	3,393	0.001
Area - Urban	-0,393	0,062	-6,383	0.000
Experience	-0,030	0,010	-3,050	0.002
Education	-0,021	0,010	-2,167	0.030
Summary statistics				
Minimum Function Test	62,19			
Degrees of freedom	10			
Goodness of fit				
SRMR	**0,032**			
RMSEA	0,096			
CFI	0,823			
TLI	0,682			

The obtained value of SRMR (0.032) for this model is statistically accepted (<0,08) proving that the overall SEM is suitable. Furthermore, the other three goodness-of-fit measures are close to the respective limits. Then, the respective path diagram is presented in Figure 5.16.

It is noted that green lines express a positive correlation while red lines express a negative one. Furthermore, dashed lines indicate which variables create the latent one (first part of the SEM) while continuous lines indicate which variables exist in the regression part of the SEM. Finally the label values represent the standardized parameter estimates.

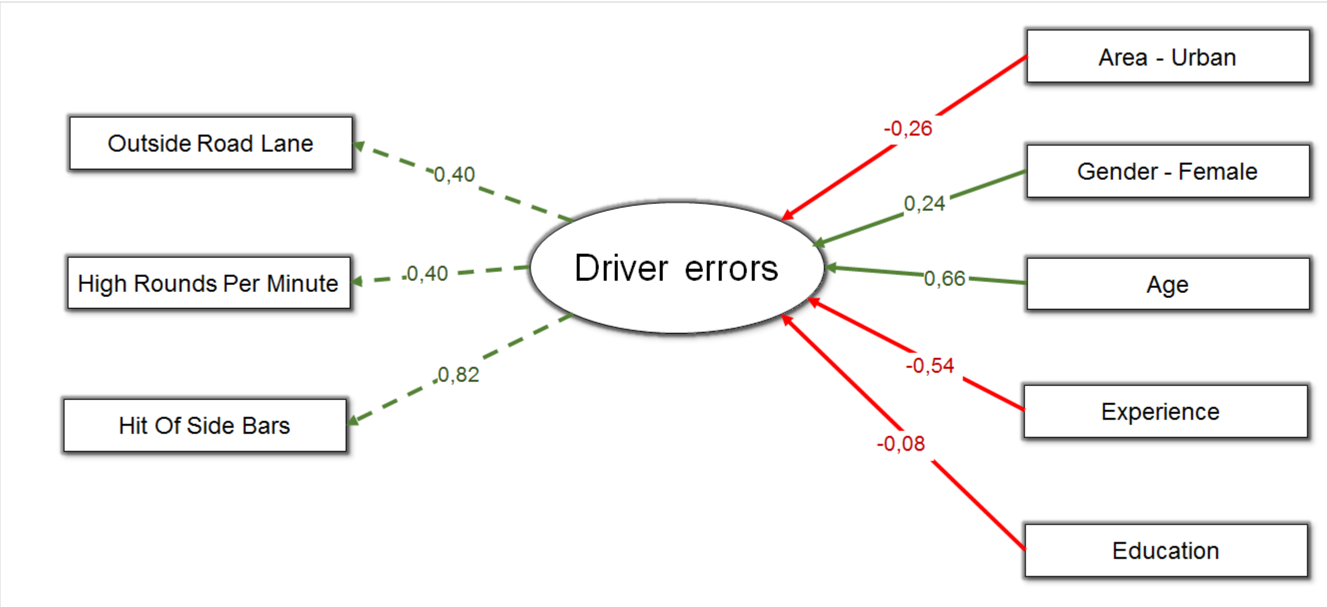

Figure 5.16 Path diagram of the driver error SEM

Driver errors (the latent variable) is positively estimated by three driving simulator variables (number of hit of side bars, number of outside road lanes, and number of high rounds per minute). It should be noted again that the creation of the unobserved variable is in absolute agreement with the respective explanatory factors analysis presented in the previous section.

For the regression part of the structural equation model, driver error is the dependent variable while the independent variables include road environment characteristics (area type) as well as driver characteristics (age, gender, experience, education).

A first and very interesting finding of this structural equation model is that neither conversing with a passenger nor talking on the cell phone has a statistical significant impact on driver errors. This fact does not mean that driver distraction does not lead drivers on committing errors at all. Driver distraction may contribute to errors through a range of means: by affecting cognitive processes such as perception, planning, decision making, and situation awareness, as well as by interfering with vehicle control tasks. However based on the finding of the present statistical analysis the effect of driver characteristics as well as area type is much higher than the effect of distraction on driving errors. Drivers in the framework of compensatory behaviour are more concentrated when being distracted and seem that they fall in less driving errors. Consequently, the increased accident risk of distracted driver is due to other factors than their errors such as the inability to cope with the errors of other drivers and other unexpected incidents.

Furthermore, results show that driver characteristics are the main cause of driver errors as several driver parameters have a statistically significant impact on the model. More specifically, gender and age have a positive sign indicating that female drivers as well as older drivers are more likely to perform driving errors. Regarding gender, this finding confirms the initial hypothesis that female drivera are worst performing and are more likely to be involved in a dangerous situations based on their own error. Furthermore, reganding the effect of age, young drivers have better mental and psysical characteristics than older drivers preventing them from commiting errors. On the other hand, both drivers' experience and education have a negative sign indicating that a more experienced and more educated driver is less likely to perform driving errors. This finding probably means that both these driver characteristics help the driver to properly handle a potentially hazardous situation and protect him from committing an error.

With regards to the driving environment only the area type is significantly affecting driver errors as in rural areas drivers are more likely to get involved in risky driving situations. This is might explained by the fact that in rural area drivers achieve higher speed and are less concentrated which leads them to be weaker on committing errors.

5.4.3 SEM regarding driver error and driving performance

The aim of the present analysis is to investigate the effect of driver characteristics, road and traffic environment, distraction sources as well as driver error on driving performance. For this purpose, two latent variables are created based on the respective structural equation models of the previous sections. The first reflects the underlying driving performance of the participants and the second reflects driver errors.

In the second part of the structural equation model, driving performance is the dependent variable while the independent variables include driver errors as well as several driver characteristics. Furthermore, another regression is taking place correlating driver errors with several risk factors. The graphical structure of the present SEM is presented in figure 5.17.

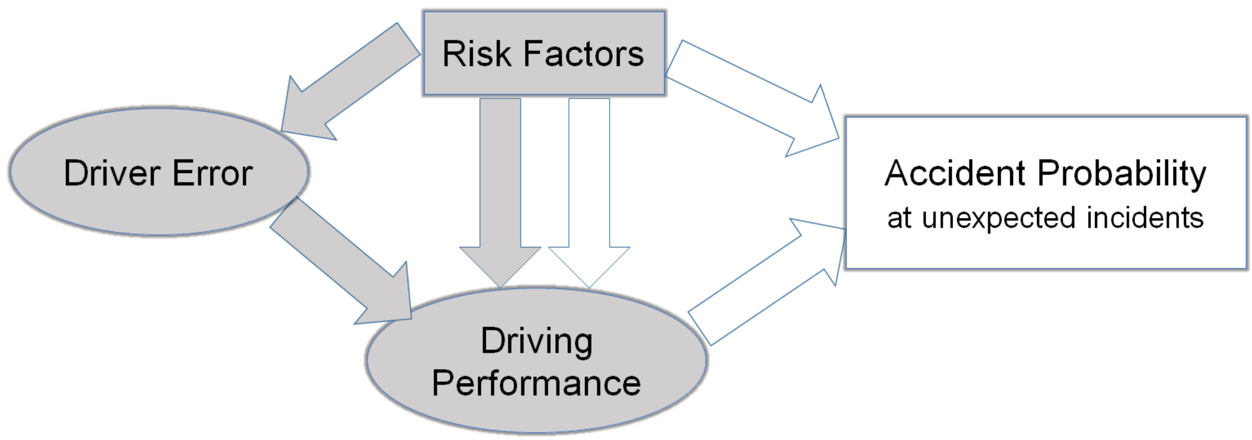

Figure 5.17 Graphical structure of driver error and driving performance SEM

The estimation results are presented in Table 5.21. It is shown that the unobserved (latent) variable which reflects driver error consists of three variables: Hit of Side Bars, Outside Road Lanes and High Rounds per Minute while the unobserved (latent) variable which reflects driving performance consists of four variables: average speed, standard deviation of lateral position, average brake, and average time to line crossing.

The obtained value of SRMR (0.105) for this model is statistically accepted as it is slightly higher than the limit (<0,08) showing that the overall structural equation model is suitable. Furthermore, the other three goodness-of-fit parameters are close to the respective limits. The respective path diagram is presented in Figure 5.18

Table 5.21 Estimation results of driver error and driving performance SEM

	Est.	Std.err	t value.	P(>|z|)
Latent Variable 1				
Driver Errors				
Hit Of Side Bars	1,000	-	-	-
Outside Road Lanes	0,547	0,214	2,559	0,010
High Rounds Per Minute	0,950	0,276	3,436	0,001
Latent Variable 2				
Driving Performance				
Average Speed	1,000	-	-	-
Stdev Lateral Position	-0,085	0,004	-23,117	0,000
Average Gear	0,049	0,002	22,043	0,000
Average TTL	-0,108	0,005	-20,114	0,000
Regression 1				
Driving Performance				
Driver Errors	-51,016	11,417	4,468	0.000
Gender – Female	-16,739	3,799	-4,407	0.000
Age	-2,244	0,681	-3,297	0.001
Experience	2,103	0,694	3,031	0.002
Regression 2				
Driver Errors				
Gender - Female	0,311	0,076	4,068	0.000
Age	0,042	0,010	4,125	0.000
Area - Urban	-0,300	0,068	-4,395	0.000
Experience	-0,040	0,011	-3,815	0.000
Education	0,004	0,001	3,174	0.002
Summary statistics				
Minimum Function Test	608,01			
Degrees of freedom	40			
Goodness of fit				
SRMR	**0,088**			
RMSEA	0,158			
CFI	0,793			
TLI	0,711			

It is noted that green lines express a positive correlation while red lines express a negative one. Furthermore, dashed lines indicate which variables create the latent one (first part of the SEM) while continuous lines indicate which variables exist in the regression part of the SEM. Finally the label values represent the standardized parameter estimates.

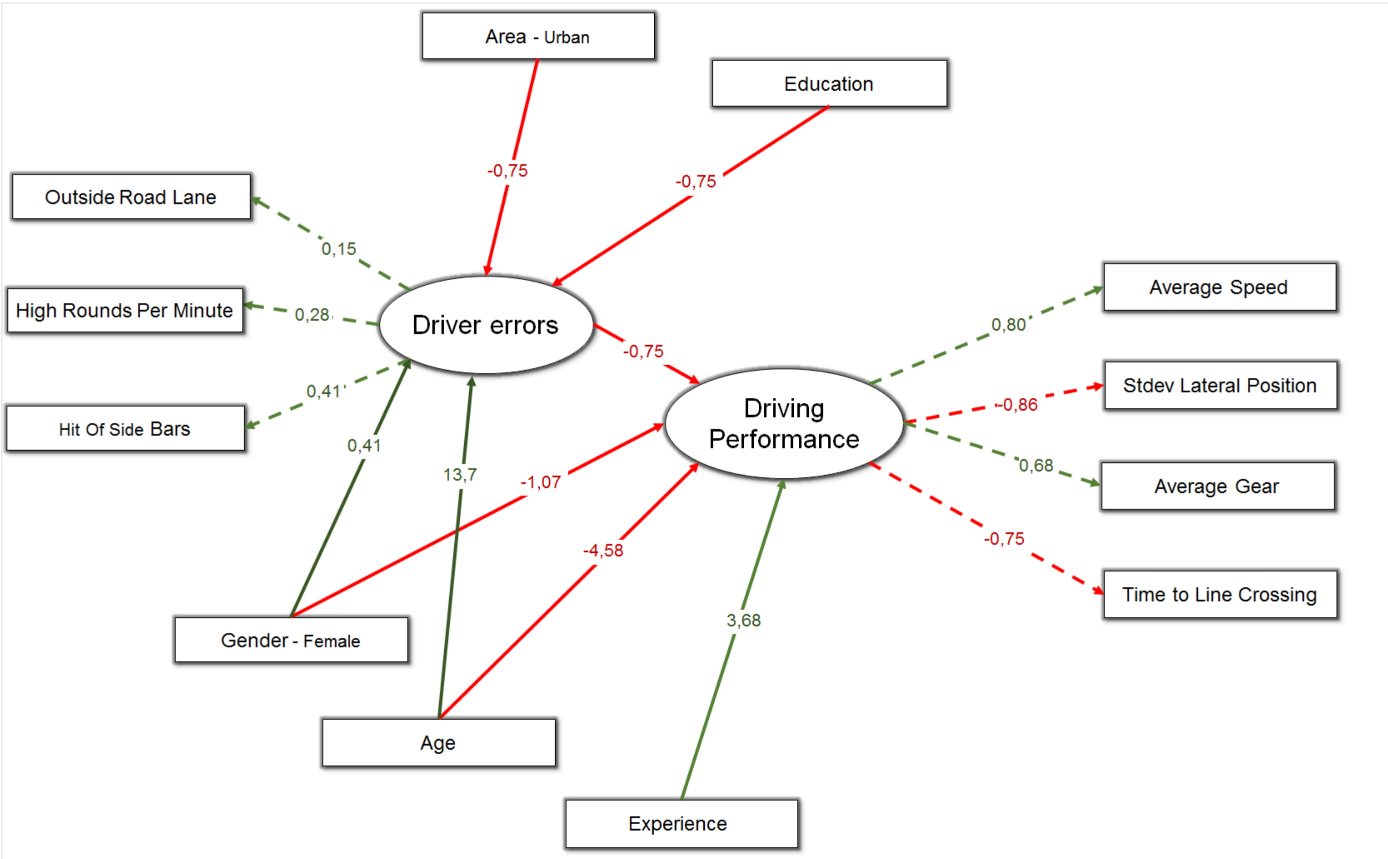

Figure 5.18 Path diagram of driver error and driving performance SEM

In the present structural equation model, two latent variables exist regarding driving performance and driver errors. In the second part of the model, two regression anaylises are taking place. In the first, driving peformance is the dependent variable while the independent variables include driver error as well as driver characteristics (age, gender, experience). In the second driver error is the dependent variable while the independent variables include age, gender, area and traffic conditions.

Results confirm the initial hypothesis that driver error is a critical factor that negatively affects driving performance. Although driver error is a latent variable, it has a high effect on the estimation of driving performance indicating that the commitment of driving errors determines at a high level the driving performance of each driver.

Furthermore, neither driving characteristics (area type, traffic conditions) nor the distraction sources examined (cell phone use, conversation with a passenger) have a significant impact on driving performance. This is probably explained by the fact that the effect of these parameters is very weak compared to the effect of driver errors as well as driver characteristics. In addition, another possible explanation is that the effect of road and traffic characteristics and distraction sources has been incorporated in the latent value of driver errors.

As a result, these individual variables have already been taken into account and therefore, they are not affecting driving performance stand alone.

Finally several driver characteristics is proved to affect, together with driving errors, driving performance. More specifically driver experience has a positive sign on driving performance indicating that an experienced driver performs much better than an unexperienced one in both driving environments and under both types of distraction. In addition, age and gender are the other two variables that have a significant effect on the statistical model. Female as well as older drivers seem to achieve worst driving performance compared to male and younger ones respectively, confirming the findings extracted in the first structural equation model regarding both driver characteristics.

5.4.4 SEM regarding accident probability

The objective of the SEM is the quantification of the impact of driving performance, driver distraction, driver as well as road environment characteristics directly on accident probability. Accident probability refers to the proportion of unexpected incidents resulting in accidents. It should be noted that in each driving trial two unexpected incidents occurred.

In order to achieve this objective, the present SEM includes one latent variable, which reflects the underlying driving performance of the participants. In the second part of the SEM “Accident risk” is the dependent variable while driving performance as well as the cell phone use, driver and road characteristics are the independent variables. The graphical structure of the present SEM is presented in figure 5.19.

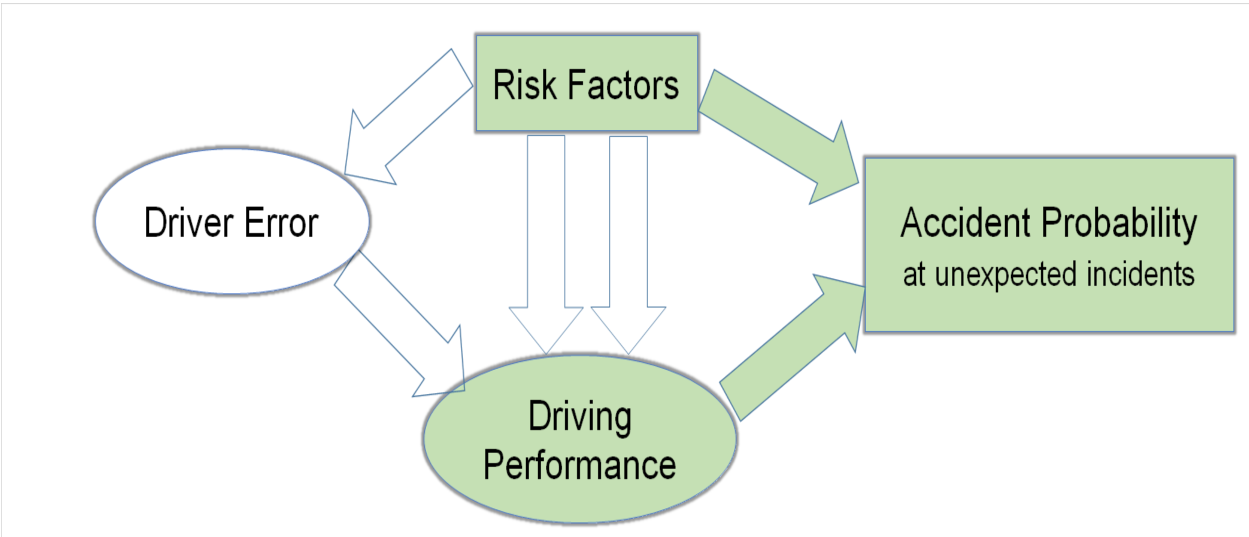

Figure 5.19 Graphical structure of SEM regarding accident probability

The estimation results are presented in Table 5.22. It is shown that the unobserved (latent) variable which reflects driving performance consists of four variables: average speed, standard deviation of lateral position, average brake, and average time to line crossing.

It is noted that green lines express a positive correlation while red lines express a negative one. Furthermore, dashed lines indicate which variables create the latent one (first part of the SEM) while continuous lines indicate which variables exist in the regression part of the SEM. Finally the label values represent the standardized parameter estimates.

Table 5.22 Estimation results of SEM regarding accident probability

	Est.	Std.err	t value.	P(>|z|)
Latent Variable				
Driving Performance				
Average Speed	1,000	-	-	-
Stdev Lateral Position	-0,085	0,004	-23,803	0.000
Average Gear	0,048	0,002	21,836	0.000
Average TTL	-0,109	0,005	-20,046	0.000
Regression				
Accident				
Driving Performance	-0,007	0,002	-3,119	0.002
Gender - Female	0,074	0,034	2,198	0.028
Traffic – Low	0,104	0,033	3,142	0.002
Distraction – Cell phone	0,081	0,033	2,463	0.014
Regression				
Driving Performance				
Gender - Female	-1,147	0,307	-3,737	0.000
Area - Urban	-15,614	0,468	-33,386	0.000
Distraction – Cell phone	-1,099	0,343	-3,208	0.001
Traffic - Low	1,131	0,286	3,956	0.000
Age	-0,156	0,028	-5,593	0.000
Experience	0,083	0,032	2,557	0.011
Summary statistics				
Minimum Function Test	352,62			
Degrees of freedom	31			
Goodness of fit				
SRMR	**0,061**			
RMSEA	0,136			
CFI	0,867			
TLI	0,807			

The obtained value of SRMR (0.061) for this model is statistically accepted (<0,08) proving that the overall structural equation model is suitable. Furthermore, the other three goodness-of-fit parameters are close to their respective limits. In the next step the respective path diagram is presented.

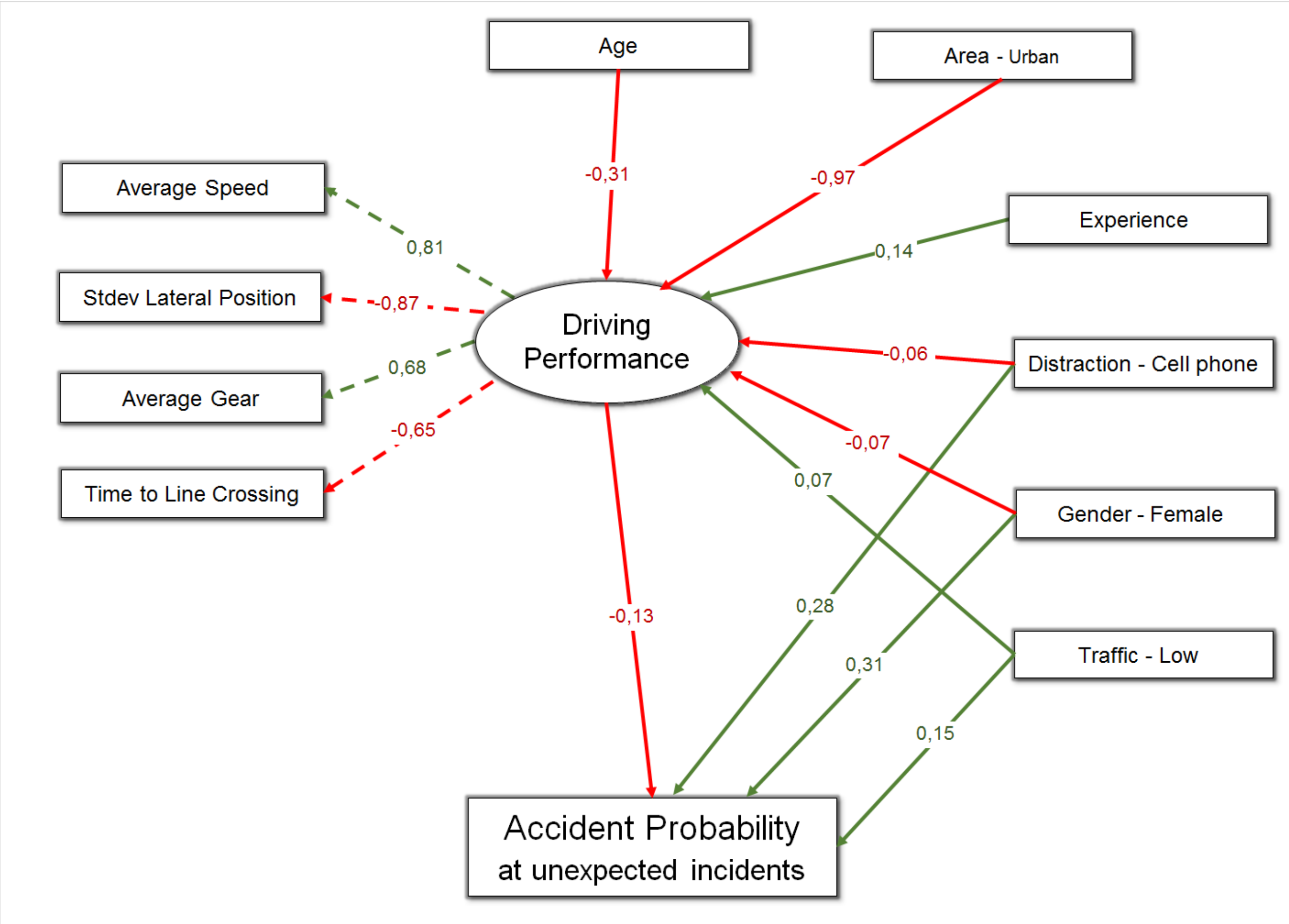

Figure 5.20 Path diagram of SEM regarding accident probability

The results of the described structural equation model suggest all the statistically significant factors that are critical for accident probability at an unexpected incident. More specifically, in the second part of the structural equation model, two regression analyses are taking place. In the first, accident risk is the dependant variable while the independent variables consist of driving performance, gender, traffic conditions as well as cell phone use. Furthermore, another regression is correlating sevral risk factors with driving performance.

Regarding driver distraction, from the two differenet distraction sources examined, only **cell phone** use is found to have a slightly negative effect on accident risk. Confirming the literature and the previous findings of the present PhD thesis, that cell phone use has a significant effect on several driving performance measures, this structural equation model indicates that when talking on the cell phone drivers find it difficult to handle an unexpected incident and as a result are more likely to commit an accident. On the other hand, the variable conversation with a passenger, does not appear in this model indicating that drivers self-regulate their driving performance better while conversing with a passenger and as a consequence react better and are less involved in accidents at unexpected incidents.

Regarding driver characteristcs, the only parameters that is significant in this model is gender, indicating that **female drivers are more prone** to accidents at unxpected inicidents than male drivers. This is probably explained by the fact that females cannot handle an unexpected incident and although they drive less aggressive generally than male drivers, at unexpected indicents are more likely to get invovled in accidents.

Finally, regarding road environment characteristics, **low traffic** is shown to positively affect accident risk. This is might explained by the fact that in low traffic conditions drivers achieve higher speed compared to high traffic conditions and in addition are less concentrated due to the simple road environment. These two reasons probably lead to the higher accident risk that occurs in low traffic conditions.

5.5 Results overview

In the present chapter an **innovating statistical analysis** methodology has been developed and presented in order to investigate all the critical parameters that affect driving performance and driver errors and then to correlate for the first time driving performance, driver rad and traffic characteristics with accident risk.

The developed methodology consists of **four individual analyses**: Descriptive analysis, regression analysis, factor analysis as well as latent analysis. All different statistical analyses provide remarkable findings for this dissertation research.

Within the framework of **descriptive statistics**, several boxplots were developed correlating average sped and reaction time of drivers at unexpected incidents with different types of distraction, driver as well as road characteristics. The basic conclusions of the descriptive analysis of the large database are the following:

Regarding **average speed**

- While conversing with the passenger drivers do not significantly change their speed. On the other hand, talking on the cell phone, decreases the average speed as part of the compensatory distracted behaviour, especially for young and middle aged drivers.
- In all distraction situations average speed is higher in rural road and in high traffic, as expected.

Regarding **reaction time**

- While talking on the cell phone or conversing with a passenger, drivers of all age groups have higher reaction times compared to undistracted driving indicating an indirect effect of distraction on accident risk.
- Young and middle aged drivers of both genders are characterized by higher reaction times when conversing with a passenger than when talking on the cell phone indicating the different distraction mechanism of the two distraction sources.

In the second part of the overall statistical methodology the implementation of **six generalised linear mixed model** is taking place regarding the following driving performance measures: average speed, reaction time, lateral position, space headway, speed variability and lateral position variability. The basic conclusions regarding each individual regression model are the following.

- Regarding **average speed**, area type has the highest effect as drivers in rural area drive in highest speed. Furthermore, the use of a cell phone while driving results in reduced speeds for all drivers. It can be assumed that the reduction in vehicle speeds of drivers using their cell phone results in a road safety benefit, given that lower travel speeds are generally correlated with lower accident risk. However, it is also an indication of the drivers' attempt to counter-balance the increased mental workload resulting from the activity in addition to the physical distraction of the handheld mode. It should be noted that while conversing with the passenger, drivers do not change significantly the average speed.

- While talking on the cell phone or conversing with passenger, drivers of all age groups achieved higher **reaction times** compared with undistracted driving. In addition, it is worth noting that young and middle aged drivers indicate higher reaction times when conversing with the passenger than talking on the cell phone explained by the different distraction mechanism between cell phone and conversation with the passenger which is correlated with driver's age. Furthermore, female drivers, especially in rural areas, were found to have the worst reaction times, while being distracted (either conversing with a passenger or talking on the cell phone). This is probably explained by the fact that in urban area, the complex road environment alerts the drivers in order to self-regulate their driving to compensate for any decrease in attention to the driving task.

- Cell phone use slightly increases **lateral position** indicating that drivers find difficult to keep the vehicle in a constant distance from the right board of the lane probably due to the fact that while talking on the cell phone they hold the steering wheel with one hand. On the contrary, conversing with a passenger was not found to affect significantly the lateral position of the vehicle. Regarding driver characteristics male drivers were found to achieve lower lateral position than the female ones confirming the literature that males drive more steadily compared to female drivers. Moreover, older drivers achieve higher lateral position proving that they find difficulties in maintaining the driving simulator vehicle compared to young drivers, especially when being distracted.

- Regarding **space headway**, cell phone use significantly increases the average space headway which is probably explained by the drivers' compensatory behaviour while talking on the cell phone which leads to larger average distances in order to counter-balance the increased mental workload resulting from the activity. On the other hand, conversing with a passenger is not found to affect the average space headway. Regarding driver characteristics male drivers tend to keep smaller space headways compared female drivers indicating that male drivers drive more aggressively. In addition, older drivers tend to keep much higher distance from the vehicle ahead compared to young and middle aged drivers. This is might be explained by the fact that older drivers feel more vulnerable while being distracted compared to young and middle aged ones and in order to compensate their driving performance and feel safer while driving, they keep much longer distance from the vehicle in front.

- Cell phone use is found to decrease **speed variability**. This is another outcome of the compensatory behaviour of drivers who tend to drive in lower speeds and with decreased speed variability when talking on the cell phone in order to counterbalance the increased mental and physical weight of the distraction activity. Regarding the road environment, speed variability is higher in rural areas and in high traffic. In both conditions, drivers achieve higher average speeds under all types of distraction which probably explains the result of higher speed variability.

- Cell phone use slightly increases **lateral position variability** indicating that drivers while talking and holding the cell phone find difficult to maintain the vehicle probably due to the fact that they hold the steering wheel with one hand while the second hand holds the cell phone. Regarding road environment characteristics, area type has the highest effect on lateral position variability indicating that lateral position variability is higher in urban areas, which could be explained by the fact that the urban environment is more complex with much more interactions between vehicles**.**

In the third part of the overall statistical methodology the implementation of **two factor analyses** is taking place in order to investigate which observed variables are most highly correlated with the common factors of driving performance and driver error and how many common factors are needed to give an adequate description of the data. Results indicate that:

- The factor analysis regarding **driving performance** resulted that 5 factors are best fitted in the specific database. The interpretation of the results revealed that the five factors are: lateral measures, speed measures, vehicle direction measures, headway as well as vehicle revolvation.
- The factor analysis regarding **driver error** demonstrated that one factor underlines driver's error while the variables that tend to explain better the new "Driver Error" factor are numbers of Outside Road Lines, Sudden Brakes and High Rounds per Minute.

Finally in the fourth step, the central point of the statistical analysis of the present PhD thesis is taking place including the implementation of structural equation models for the first time in the scientific field of driver distraction. Within the framework of latent analysis, four **Structural Equation Models** are implemented aiming to investigate the quantification of the impact of driver distraction, driver characteristics and road environment **directly** on driving performance, driver errors and accident probability at unexpected incidents. The basic conclusions for each individual SEM are the following:

Regarding **driving performance**:

- Conversation with the passenger was not found to have a statistically significant effect proving that drivers do not change their performance while conversing with a passenger compared to undistracted driving.
- The effect of cell phone on driving performance is negative probably based on two contradictory factors. Firstly, due to the amount of physical and mental resources that required to perform the distraction task. Secondly, within the framework of the compensatory behaviour due to which drivers change their driving performance in order to counterbalance the distraction activity.
- Regarding driver characteristics, both age, gender and experience are significant indicating that driver characteristics play the most crucial role in driving performance. More specifically, results indicate that driving performance is negatively affected for female and age. Regarding gender, this finding confirms the initial hypothesis that female driver are worst performing than male drivers, especially when being distracted. Furthermore, reganding the effect of age, young drivers are better familiarised with the use of cell phone and as a consequence their driving performance is better than middle aged and older driver who find difficulties in maintaining their performance when being distracted. However, this effect is partially coutnerbalanced by the fact that experience is important in the driving performance as proved by the statistical model above.
- Regarding area and traffic environment characteristics, area type is proved to be the most significant factor that affects drivers’ performance as in urban areas driving performance was negatively affected. This is probably explained by the more complex road environment in urban areas.

Regarding **Driver error**:

- Neither conversing with a passenger nor talking on the cell phone has a statistical significant impact on driver errors. Based on the finding of the present statistical analysis the effect of driver characteristics as well as area type is much higher than the effect of distraction on driving errors. Drivers in the framework of compensatory behaviour are more concentrated when being distracted and seem that they fall in less driving errors. Consequently, the increased accident risk of distracted driver is due to other factors than their errors (e.g. inability to cope with the errors of other drivers or other incidents).
- Driver characteristics are the main cause of driving errors as expected. Gender and age have a positive sign indicating that female drivers as well as older drivers are more likely to perform driving errors. Regarding gender,

this finding confirms the initial hypothesis that female driver are worst performing than males drivers, and are more likely to be involved in a dangerous situations based on their own error. Furthermore, young drivers have better mental and physical characteristics than older drivers which prevents them from committing driving errors

- Both drivers' experience and education help the driver to properly handle a potentially hazardous situation and protect him from committing an error.
- Area type is significantly affecting driver errors as in rural areas drivers are more likely to get involved in risky driving situations. This is might explained by the fact that in rural area drivers achieve higher speed and are less concentrated which leads them to be weaker on committing errors.

Regarding the effect of **driver error** on driving **performance**:

- Results confirm the initial hypothesis that driver error is a cricial factor that negatively affects driving performance.
- Neither road characteristics (area type, traffic conditions) nor the distraction sources examined (cell phone use, conversation with a passenger) have a significant impact on driving performance. This is probably explained by the fact that the effect of these parameters is very weak compared to the effect of driver errors as well as driver characteristics. In addition, another possible explanation is that the effect of driving characteristics and distraction sources has been incorporated in the latent value of driver errors. As a result, these individual variables have already been taken into account and therefore, they are not affecting driving performance stand alone.
- Driver experience has a positive sign on driving performance indicating that an experienced driver performs much better than an unexperienced one in both driving environments and under both types of distraction.
- Female as well as older drivers seem to achieve worst driving performance compared to male and younger ones respectively, confirming the findings extracted in the first structural equation model regarding both driver characteristics.

Regarding **accident probability at unexpected incidents**:

- Cell phone use has a negative effect on accident probability based on the result of this structural equation model which indicates that when talking on the cell phone drivers find it difficult to handle an unexpected incident and as a result are more likely to commit an accident
- Drivers self-regulate their driving performance better while conversing with a passenger and as a consequence react better and are less involved in accidents at unexpected incidents.
- Female drivers are more prone to accidents at unxpected inicidents than male drivers. This is probably explained by the fact that females cannot handle an unexpected incident and although they drive less aggressive generally than male drivers, at unexpected indicents are more likely to get invovled in accidents.
- Low traffic is proved to positively affect accident risk. This is might explained by the fact that in low traffic conditions drivers achieve higher speed compared to high traffic conditions and in addition are less concentrated.

6. Conclusions

6.1 Overview of the research

The objective of the present PhD thesis is the **analysis of the effect of road, traffic and driver risk factors on driver behaviour and accident probability at unexpected incidents**, with particular focus on distracted driving. For this purpose, a specially developed methodology is implemented which consists of 4 discrete steps:

- The first step concerns a comprehensive literature review fully covering the research topics examined.
- In the second step a methodological review is taking place regarding driving performance measures and statistical analysis techniques.
- In the third step, a large driving simulator experiment is carefully designed and implemented.
- In the fourth step an innovative statistical analysis methodology is developed including four different types of analyses.

Beginning with the **first step**, an extensive literature review is carried out, investigating in a comprehensive way the research **topics** examined: driving behaviour, driver distraction and its assessment methods, driving simulator characteristics as well as driving simulator studies on driver distraction.

More specifically, starting with a review of **driving behaviour** parameters, an overview of human factors related to driver behaviour as well as cognitive functions critical for safe driving are presented and analysed. Then several definitions are considered regarding the terms of **driver distraction** and driver inattention and their differences are highlighted while the distraction accident mechanism is investigated and the types of driver distraction are analysed. Within this framework, driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). Driver distraction factors that occur inside the vehicle seem to have greater effect on driver behaviour and safety. In addition, driver distraction may have an impact to driver attention (i.e. hands-off the wheel, eyes-off the road), driver behaviour (i.e. vehicle speed, headway, vehicle lateral position, driver reaction time) and driver accident risk. Furthermore, driver distraction factors are categorized according to whether they are occurring inside or outside the vehicle and the critical point of compensatory behaviour of drivers is thoroughly investigated.

In addition, an extended literature review is carried out regarding all available **experiment types** of assessing driving performance. More specifically, benefits and limitations are explored and presented regarding Naturalistic Driving Experiments, Driving Simulator Experiments, On Road Experiments, In Depth Accident Investigations and Surveys on Opinion and Stated Behaviour. It is concluded that the selection of method for the assessment of driver performance should be carried out in accordance to the specific objectives or research questions of the assessment, the time-frame and the infrastructure or resources available. In the present research, a driving simulator experiment is opted for, given that it allows the investigation of various risk factors in a safe and controlled environment. Consequently, information regarding the validity and fidelity of driving simulators are provided, while the phenomenon of simulator sickness is explored.

Another major part of the literature review consisted of an exhaustive review on **driving simulator studies on driver distraction** indicating that although simulator studies on driver distraction provide useful insights into how driver, vehicle, and roadway characteristics influence distracted driving behaviour and safety, the design and implementation of such experiments is very often inconsistent and they do not always conform to experimental design principles. Overall, the findings of this review highlight the need for larger scale simulator studies (larger and more representative samples), more standardised experiment designs and more uniform measures of driver distraction. Dealing with these challenges is a critical component of the design of the distracted driving simulator experiment carried out within the present research. Furthermore, key characteristics of the sample being investigated need to be examined with caution, including age distribution (mean and range), gender, mental status, cognitive functions, visual function, while participants' recruitment process is also likely to be a critical component of the sampling scheme.

On the basis of the **comparative assessment** of these studies, it is found that at the majority of studies, the most common distraction sources examined are cell phone use, conversation with passengers and visual distraction, as well as their comparisons. Most experiments are based on very small samples, limited to rural road environment, with non-explicit (if at all) simulation of ambient traffic. No pattern could be identified as regards the selection of number and duration of trials. Moreover, it is a matter of some concern that the size of the experiment is not adequately adjusted to the sample size in several studies.

The **second step** of the present PhD thesis concerns the choice of the methodological approach allowing to address in an innovative way the research challenges mentioned above. For this purpose, an additional targeted literature review took place in order to investigate the key driving performance measures examined in driver distraction research as well as the statistical analyses implemented in the scientific field of driver distraction. More specifically, driving performance measures examined in driving simulator experiments are presented and analysed including lateral control, longitudinal control, reaction time, gap acceptance, eye movement and workload measures.

Results indicate that while driver distraction is a **multidimensional phenomenon,** which means that no single driving performance measure can capture all effects of distraction and the selection of the examined measure should be guided by the nature of the task examined as well as the specific research questions. However, in the literature different driving performance measures are examined in different studies, most often tackling only specific aspects of driving performance. Consequently, the need for a composite driving performance measure is demonstrated.

The **third step** concerns the design and implementation of a large driving simulator experiment, allowing to address the complex challenges of this PhD thesis. All individual experiment parts are carefully designed and executed tackling the limitations and needs identified in similar driving simulator experiments reviewed in the previous chapters.

Within this framework, **95 participants** were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in different road (urban/rural) and traffic conditions (high/low). Each participant aimed to complete 12 different driving trials, while in each trial, 2 unexpected incidents were scheduled to occur at fixed points along the drive.

The above stages were designed on the basis of parameters and criteria shown to be important in the literature, as well as design principles that were appropriate for the research assumptions and objectives of the present research. Furthermore, several other information are provided concerning driving simulator characteristics, sample characteristics, the exclusion criteria as well as how researchers deal with the phenomenon of simulator sickness.

Then, regarding the **procedure** of the driving simulator experiment, the organisation of the research team is provided and the oral instructions to the participants are recorded. Furthermore, special emphasis is given to the familiarisation part as specific performance measures were used to assess the driver's familiarisation with the simulator before proceeding to the main part of the experiment. Then, the process of the main driving scenarios is described.

In the next part of the experiment, after completed the driving simulator tasks, participants were asked to fill in two **questionnaires**. The first Questionnaire concerned their driving habits and their driving behaviour while the second was a Self-Assessment Questionnaire that covered aspects related to the driving simulator experience. Then, as the dataset from the driving simulator experiment and the questionnaires is very large, information regarding the data processing is provided including data files, data storage and the processing levels, together with the sample characteristics.

In the **fourth step**, the data collected from the driving simulator experiment and the respective questionnaires are analysed by means of **an innovative statistical analysis method**. The overall statistical method consists of four types of analyses.

In the first analysis, the large size of the dataset makes the **descriptive analysis** of a large number of variables essential. Within this framework, an overview of all variables which are provided by the driving simulator is provided. Then, several boxplots are presented investigating the effect of specific driving characteristics such as age, gender, area and traffic conditions on different distracted situations on selected driving performance measures while a correlation table investigates the relationships between all pairs of variables.

Then, in the framework of the explanatory analysis, the development of **regression models** takes place (general linear models and general linear mixed models) regarding key performance parameters such as average speed, reaction time of drivers at unexpected incidents, lateral position, average headway, speed variability, and lateral position variability. Such models are often used in driver distraction analysis in order to estimate the effect of distraction sources and driving characteristics on specific driving performance parameters and indirectly on driving behaviour and road safety.

Then, **factor analysis** is implemented, as a first step towards the development of latent variables within the framework of the structural equation models, regarding driving performance and driver errors in order to investigate which observed variables are most highly correlated with the common factors and how many common factors are needed to provide an adequate synthesis of the data.

Finally in the fourth type of analysis, consisting as the central component of the statistical analysis of the present PhD thesis is taking place focusing to the development and application of structural equation models for the first time in the scientific field of driver distraction. Within the framework of latent analysis, a sequence of four **Structural Equation Models** is developed and applied aiming to investigate the quantification of the impact of driver distraction, driver characteristics as well as road and traffic environment directly on driving performance, driver errors, and accident probability. The sequence of the four different structural equation models developed is described graphically in the next figure (each arrow colour represents a different SEM) and explained below:

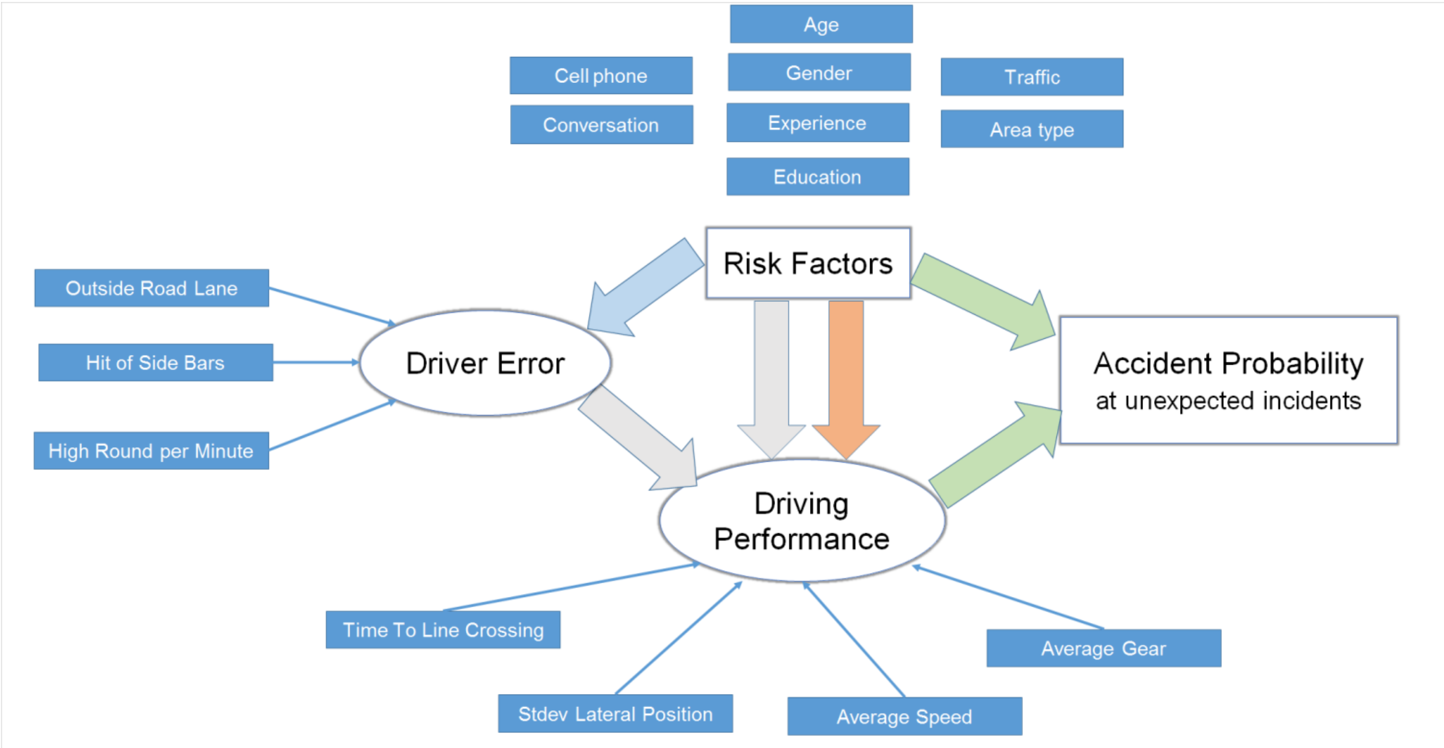

Figure 6.1 Graphical approach of latent analysis

- In the first SEM (orange arrow), the latent variable reflects the underlying **driving performance** and the objective is the quantification of the impact of distraction, driver characteristics as well as road and traffic environment on driving performance.
- In the second SEM (blue arrow), the latent variable reflects the underlying **driver error** and the objective is the quantification of the impact of distraction, driver characteristics as well as road and traffic environment on driving errors.
- In the third SEM (gey arrow), two latent variables are created regarding **driving performance and driver error** while the objective of this analysis is the quantification of the impact of driving errors, distraction, driver characteristics as well as road and traffic environment on driving performance.
- In the fourth SEM (green arrow), the latent variable reflects again the underlying driving performance of the participants and the objective is the quantification of the impact of driving performance, distraction, driver characteristics as well as road and traffic environment directly on **accident probability**.

The development and application of the above sequence of structural equation models allow the estimation of the effect of distraction as well as road, traffic and driver risk factors on driving performance. Furthermore the estimation of all the above parameters on driver errors and accident probability led to the development of specific risky driving profiles completing the puzzle of the effect of driver distraction on driver behaviour and road safety

6.2 Conclusions

The innovative outcome of the present PhD thesis consists of four original scientific contributions as presented here after (see figure 6.2). It should be noted that the first two scientific contributions refer to the methodological contribution of the research while the third and the fourth are the key research findings of this PhD. The four original scientific contributions are the following:

- A large driving simulator experiment
- An advanced statistical analysis methodology introducing latent analysis in driving performance and traffic safety
- The estimation of the combined effect of driver distraction, road, traffic and driver risk factors on driving performance and accident probability
- The development of a set of risky driving profiles

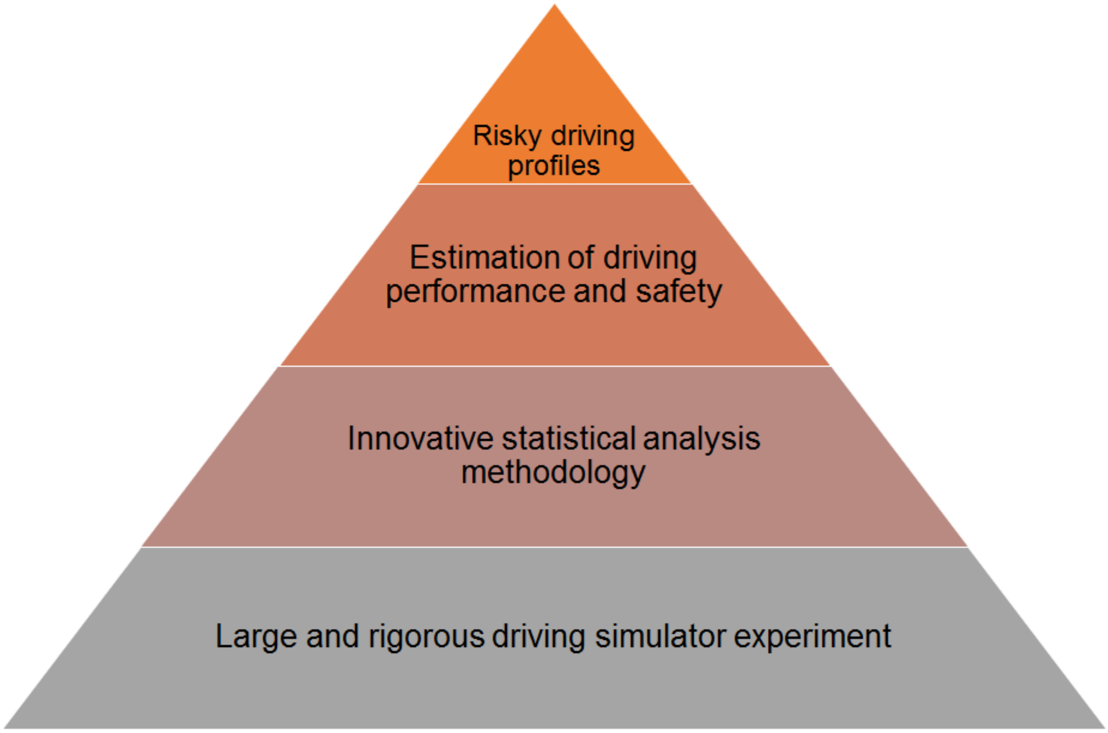

Figure 6.2 Four original scientific contributions of the PhD

6.2.1 Methodological contribution of the research

The **first** scientific contribution concerns the design and implementation of **a large driving simulator experiment** and consists the basis of the originality of the overall research**.** The design and implementation of this experiment is a central component of the present PhD thesis and it is based on all the respective literature reviews aiming to deal with the majority of limitations that have been noted in the assessment of the examined simulator studies on driver distraction. The basic limitations found in the literature that the present experiment tackled are the following:

Large and representative sample
Within the framework of the present driving simulator experiment 95 participants started the driving simulator experiment and completed, at least, 6 driving trials. Furthermore, sample analysis indicated that there is an appropriate balance in the sample regarding gender and age group distribution.

Randomisation of trials
A basic principle of the experimental design is randomisation, which is a suitable random process of assigning treatments to the experimental units. The random process implies that every possible allotment of treatments has the same probability. The purpose of randomization is to remove bias and other sources of extraneous variation, which are not controllable. In this experiment randomization was obtained in the order of the area type (urban/rural) in which the participant was going to drive, as well as in the order of the traffic and distraction scenarios.

Adequate practice drive
Another limitation tackled concerned the reporting of specific performance measures used to assess the driver's familiarization with the simulator. In the present experiment, during the familiarization with the simulator, the participant practiced in:

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

It should be noted that the following criteria were verified (without time restriction) before the participant moved on to the next phase of the experiment.

Investigation of an optimum number of driving factors
In the present driving simulator experiment, participants were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in different road (urban/rural) and traffic conditions (high/low). Furthermore, the driving factors further examined includes few other driver characteristics such as gender, age, experience and education.

The **second** original scientific contribution of the present PhD thesis concerns the development and application of an **innovative statistical analysis methodology**. More specifically, latent analysis through structural equation models is implemented for the first time in the field of driving performance and traffic safety. Latent analysis allowed an important scientific step forward from piecemeal analyses to a sound combined analysis of the interrelationship between risk factors (including driver distraction), driving performance, driver error and accident probability at unexpected incidents.

Structural equation models are designed to deal with several difficult modelling challenges, including cases in which some variables of interest to a researcher are unobservable or latent and are measured using one or more exogenous variables. For the purpose of this research, two latent variables were created: a) **driving performance** variable reflecting the underlying driving performance of the participants (on the basis of several observed driving measures such as average speed, lateral position variability, average gear, time to line crossing) and b) **driver errors** variable reflecting the driving errors of the participants (on the basis of variables indicating driving errors such as hit of side bars, outside road lanes, high rounds per minute.

6.2.2 Key research findings

The **third original scientific contribution** of the present PhD thesis concerns the estimation of the combined effect of distraction sources, driver as well as road and traffic environment characteristics directly on driving performance and accident probability.

More specifically, the development and application of the two first structural equation models, allowed the quantification of impact of several risk factors directly on the latent variable which underlines driving performance. Within this analysis, results regarding the effect of driver distraction indicate the different effect on driving performance between cell phone use and conversation with the passenger.

Conversation with the passenger was not found to have a statistically significant effect proving that drivers do not change their overall performance significantly while conversing with a passenger compared to undistracted driving. This finding can be explained by the assumption that the passengers are able to follow the road and traffic conditions and the related workload of the driver and adjust their interventions (distraction) to the driver. On the other hand the effect of cell phone on the overall driving performance was proved to be negative indicating the crucial role of cell phone use on driver behaviour and accident probability.

The change on driving performance of drivers talking on the cell phone is based on two opposing reasons. Firstly, cell phone use while driving distracts drivers in several ways including physical distraction (the driver has to use one hand in order to manipulate the telephone), visual distraction (cell phone use is consisted of prolonged and repeated glances to the cell phone) and cognitive distraction (involves lapses in attention when two mental tasks are performed at the same time). On the contrary, **compensatory distracted behaviour** is occurring which means that drivers while talking on the cell phone feel insecure and change their performance in order to counterbalance the distraction activity. Results confirm the initial hypothesis that the overall balance regarding the effect of cell phone use on driving performance and accident probability is negative.

Furthermore, the present research findings quantify the effect of several driver risk factors on the overall **driving performance**. Reganding the effect of age, young drivers are better familiarised with the use of cell phone and as a consequence their driving performance is better than middle aged and older drivers who find difficulties in maintaining their performance when being distracted. Furthermore, regarding gender, female drivers achieved lower driving performance under all types of distraction confirming the initial hypothesis that female driver are performing less well than males drivers, especially when being distracted. In addition, regarding the effect of road environment, area type is found to be the most significant factor that affects drivers' performance as in urban areas driving performance is worst in comparison to rural roads, probably due to the more complex road environment.

Finally, the **fourth original scientific contribution** of the present PhD thesis concerns the development of certain risky driving profiles as resulted from the application of the two other latent models regarding **driver errors** as well as **accident probability at unexpected incidents**.

Beginning with driver error, the present research shows that **driver characteristics** are the main cause of driver errors. More specifically, **gender** and **age** have a significant effect indicating that female drivers as well as older drivers are more likely to perform driving errors. Regarding gender, this finding confirms the initial hypothesis that female driver are worst performing than males drivers, and are more likely to be involved in a dangerous situations based on their own error. Furthermore, young drivers have better mental and physical characteristics than older drivers which prevents them from committing driving errors. On the other hand, model results proved that both drivers' **experience** and **education** assist the driver to properly handle a potentially hazardous situation and protect him/her from committing an error.

Regarding road environment risk factors, **area type** is significantly affecting driver errors as in rural areas drivers are more likely to get involved in higher risk driving situations. This is might explained by the fact that in rural area drivers achieve higher speed and can be less concentrated, which might makes them more error-prone.

Regarding the effect of distraction on driving errors, neither conversing with a passenger nor talking on the cell phone were found to have a statistically significant impact on driver errors. Based on the finding of the present research the effect of driver characteristics as well as of area type is much higher than the effect of distraction on driving errors. Drivers in the framework of compensatory behaviour are more concentrated when being distracted and seem that they fall in less driving errors. Consequently, **the increased accident risk of distracted driver is due to other factors than their errors**; e.g. inability to cope with the errors of other drivers or other incidents maybe due to increased reaction time.

Summarising the findings regarding driver errors, the first risky driving profile can be created indicating that **more likely to commit driving errors are young or old female drivers at urban areas.**

According to the second latent analysis, accident probability is estimated as the probability for the driver to have an accident at an unexpected incident. The findings of the present PhD thesis indicate that cell phone use has a statistically significant negative effect on accident probability demonstrating that drivers while talking on the cell phone find it difficult to handle an unexpected incident and as a result are more likely to get involved in an accident. This is probably explained by the fact that at unexpected incidents risk compensation strategies of the driver can not counterbalance the higher reaction time due to distraction. On the other hand, drivers (and passengers) self-regulate their driving performance better while conversing with a passenger and as a consequence react better and are less involved in accidents at unexpected incidents.

Furthermore, **female drivers** are more prone to accidents at unexpected incidents than male drivers. This is probably explained by the fact that female drivers cannot handle an unexpected situation the way male drivers do and although they generally drive less aggressive and less speedy than male drivers, at unexpected indicents they are more likely to get involved in accidents.

Finally, **low traffic** is shown to lead to increased accident probability. This is might explained by the fact that in low traffic conditions drivers achieve higher speed compared to conditions with higher traffic conditions and in addition can be more easily less concentrated due to the usually longer duration of their trips. These tho main reasons probably lead to the higher accident probability at unexpected incidents occuring in low traffic conditions.

Summarising the findings regarding accident probability at unexpected incidents, the second risky driving profile can be created indicating that **more likely to be involved in an accident at an unexpected incident are female drivers in low traffic conditions while talking on the cell phone.**

Overall, the proposed methodological approach and statistical techniques of the present research, are proved to significantly improve the potential of the analysis and provide new insights on driver behaviour and safety. The a**dded value** of the methodology, through the consideration of latent variables and the implementation of structural equation models, is found to be useful and promising, revealing new patterns such as the estimation of the effect of risk factors directly on driving performance as well the creation of specific driving profiles.

6.3 Next steps

In the present PhD thesis an original methodological and statistical concept is developed for the analysis of the effect of road, traffic and driver risk factors on driver behaviour and accident probability, with particular focus on distracted driving. The methodological as well as statistical results of the present research should be **further processed** in order to provide more valuable findings in the field of driving behaviour and driver distraction.

The innovative methodological approach which consists of the implementation of structural equation model on the basis of the creation of latent (unobserved) variables, could be further developed and applied in more **general driving behaviour scientific fields**. Within this framework, the effect of several other parameters such as fatigue or alcohol can be estimated on the unobserved variables which underline driving performance or accident risk. 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.

Furthermore, this specific methodology should be developed as well on different methods of assessing driver behaviour and distraction. More specifically, as the application of structural equation models needs a large dataset with several parameters, SEMs can be developed on **naturalistic experiments** or **field survey studies** in order to estimate the effect of the examined risk factors directly on the overall driving performance and safety of the participants.

Concentrating on the effect of **driver distractio**n, in the present research conversation with the passenger and cell phone use where deeply examined. However, several other distraction sources both inside and outside the vehicle are estimated to play a crucial role in driving behaviour and accident probability and should be further investigating regarding their effect not only to individual driving performance measures but as well to the overall unobserved driving performance.

Furthermore, as **compensatory behaviour** was found to play a quite critical role on the distracted driving performance of the present experiment, further research should examine what compensatory behaviours drivers use to trade-off and maintain an adequate level of driving and secondary task performance and which of these strategies are most effective in minimising driving degradation. In addition, research should also investigate how the compensatory behaviours adopted to reduce the effects of distraction vary as a function of age, driving experience and different levels of fitness for duty (e.g., fatigued drivers or drivers under the influence of alcohol or drugs).

Finally, regarding the **effect of cell phone**, in the present research the negative effect of cell phone was found statistical significantly both on driver performance as well as on accident probability. Therefore, it would be important to investigate, not only when the drivers talk on cell phone using a hand-held device but also when they use a hands-free device, a bluetooth, or when they type an sms. In each of the above cell phone use situations, the mental workload, the visual impairment and more importantly the physical act are very different indicating that the results both on driving performance, driver errors as well as accident probability will be very interesting and useful for the overall interpretation of the effect of cell phone use while driving.

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8. Annexes

Annex 1: Exclusion Criteria Form

Κωδικός Οδηγού ....

1. Συγκοινωνιακά κριτήρια αποκλεισμού (CT)

CT1. Έχετε δίπλωμα οδήγησης επιβατικού οχήματος εν ισχύ; ΝΑΙ – ΟΧΙ
(Αν όχι, αποκλείεται)

CT2. Πόσα χρόνια οδηγείτε; ....
(Αν <3 χρόνια, αποκλείεται)

CT3. Τους τελευταίους 12 μήνες, πόσα χιλιόμετρα κάνατε; ....
(Αν <2.500 km, αποκλείεται)

CT3a. Τους τελευταίους 12 μήνες πόσες μετακινήσεις κάνετε κατά μέσο όρο την εβδομάδα; ....
(Αν <1 μετακίνηση/εβδομάδα, αποκλείεται)

CT3b. Τους τελευταίους 12 μήνες πόσα χιλιόμετρα κάνετε κατά μέσο όρο την εβδομάδα; ....
(Αν <10 km/εβδομάδα, αποκλείεται)

2. Ιατρικά κριτήρια αποκλεισμού (CM)

CM1. Πόσος είναι ο δείκτης CDR; ....
(Αν ≥2, αποκλείεται)

CM2. Υπάρχει σημαντικό ψυχιατρικό ιστορικό για ψύχωση; ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

CM3. Έχετε κάποια σοβαρή κινητική διαταραχή που να εμποδίζει την οδήγηση κανονικού αυτοκινήτου (π.χ δυσκολία στον χειρισμό χειροκίνητου κιβώτιου ταχυτήτων, δυσκολία στη χρήση του πεντάλ σύμπλεξης); ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

CM4. Έχετε ίλιγγο, ναυτία κατά την οδήγηση, είτε ως οδηγός, είτε ως συνοδηγός;
ΝΑΙ – ΟΧΙ
(Αν ναι, αποκλείεται)

CM5. Είστε έγκυος; ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

CM6. Είστε αλκοολικός ή έχετε κάποια εξάρτηση από άλλες ουσίες; ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

CM7. Έχετε κάποια οφθαλμική πάθηση που να απαγορεύει νομικά την οδήγηση (πχ Οπτική οξύτητα <10/20 και για τους 2 οφθαλμούς); ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

CM8. Έχετε κάποια πάθηση του Κεντρικού Νευρικού Συστήματος (ΚΝΣ) που είναι εκτός των παθήσεων που εξετάζονται στην παρούσα μελέτη (π.χ Όγκοι ΚΝΣ, Σκλήρυνση κατά Πλάκας, Επιληψία κλπ); ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

Annex 2: Driving behaviour Questionnaire

Το ερωτηματολόγιο το συμπληρώνει ο/η______________________________

(οι ερωτήσεις αφορούν τον εαυτό του)

Κωδικός Συμμετέχοντα:	Q1.0.1		
Ονοματεπώνυμο Συμμετέχοντα:	Q1.0.2		
Ημερομηνία συμπλήρωσης:	Q1.0.3		
Ηλικία:	Q1.0.4		
Φύλο (κυκλώστε):	Q1.0.5	Άντρας (1)	Γυναίκα (2)

Α. ΟΔΗΓΙΚΗ ΕΜΠΕΙΡΙΑ - ΜΕΤΑΚΙΝΗΣΕΙΣ

1. Πόσα χρόνια οδηγείτε;	Q1.1							
2. Σας αρέσει η οδήγηση (κυκλώστε);	Q1.2	Ναι (1)		Όχι (2)				
3. Πότε αποκτήσατε την άδεια οδήγησης σας;	Q1.3							
4. Πότε λήγει η άδεια οδήγησης σας;	Q1.4							
5. Είσαστε ή ήσασταν επαγγελματίας οδηγός (κυκλώστε);	Q1.5	Ναι (1)		Όχι (2)				
6. Πόσες ημέρες την εβδομάδα χρησιμοποιείτε το αυτοκίνητό σας (κυκλώστε);	Q1.6	1	2	3	4	5	6	7
7. Πόσα χιλιόμετρα περίπου οδηγείτε την εβδομάδα (κυκλώστε);	Q1.7	<20	20-50	50-100	100-150	150+	Δεν ξέρω	
8. Πόσες διαδρομές πραγματοποιείτε την ημέρα ως οδηγός (κυκλώστε);	Q1.8	1	2	3	4	5+		
9. Υποδείξτε το μέσο μήκος των διαδρομών σας σε χιλιόμετρα (κυκλώστε):	Q1.9	1-2	3-5	6-9	10-15	16-29	30+	Δεν ξέρω
10. Σε σχέση με πέντε χρόνια πριν η οδήγησή σας (κυκλώστε):	Q1.10	Έχει περιορισθεί (1)	Είναι η ίδια (2)	Έχει αυξηθεί (3)	Δεν ξέρω (4)			

11. Πόσο συχνά οδηγήσατε το τελευταίο εξάμηνο στις παρακάτω συνθήκες:

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	Καθόλου	Τουλάχιστον μια φορά το δίμηνο	Τουλάχιστον μια φορά τον μήνα	Τουλάχιστον μια φορά τη βδομάδα	Τουλάχιστον δύο φορές τη βδομάδα	Τουλάχιστον τέσσερις φορές τη βδομάδα
Q1.11.1	Νύχτα	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.2	Σε ώρες κυκλοφοριακής αιχμής	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.3	Με βροχή	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.4	Σε αυτοκινητόδρομους	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.5	Σε άγνωστες περιοχές	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.6	Εκτός πόλης	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.7	Εντός πόλης	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.8	Κοντά στην περιοχή κατοικίας σας	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.9	Διανύοντας μεγάλες αποστάσεις (>2ώρες)	(1)	(2)	(3)	(4)	(5)	(6)

12. Πόσες φορές το τελευταίο εξάμηνο αποφύγατε επισκέψεις ή άλλες δουλειές με το αυτοκίνητό σας επειδή ανησυχείτε για την οδήγηση σας (κυκλώστε);

Q1.12	Ποτέ (1)	Σπάνια (2)	Μερικές φορές (3)	Πολλές φορές (4)

Β. ΑΥΤΟΑΞΙΟΛΟΓΗΣΗ ΟΔΗΓΟΥ

13. Ποιά είναι τα αδύνατα και ποιά τα δυνατά σημεία σας στην οδήγηση;

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	Αδύνατο	Λίγο αδύνατο	Μάλλον δυνατό	Δυνατό
Q1.13.1	Να οδηγείτε μακρινές αποστάσεις	(1)	(2)	(3)	(4)
Q1.13.2	Να αντιλαμβάνεστε άμεσα τους κινδύνους της κυκλοφορίας	(1)	(2)	(3)	(4)
Q1.13.3	Να οδηγείτε σε ολισθηρό δρόμο	(1)	(2)	(3)	(4)
Q1.13.4	Να αλλάζετε λωρίδα κυκλοφορίας με άνεση	(1)	(2)	(3)	(4)
Q1.13.5	Να παίρνετε γρήγορες αποφάσεις όταν οδηγείτε	(1)	(2)	(3)	(4)
Q1.13.6	Να παραμένετε ψύχραιμοι σε αγχωτικές καταστάσεις όταν οδηγείτε	(1)	(2)	(3)	(4)
Q1.13.7	Να ελέγχετε απόλυτα το αυτοκίνητο	(1)	(2)	(3)	(4)
Q1.13.8	Να αφήνετε αρκετή απόσταση από το μπροστινό αμάξι	(1)	(2)	(3)	(4)
Q1.13.9	Να προσαρμόζετε την ταχύτητά σας ανάλογα με τις οδικές καταστάσεις	(1)	(2)	(3)	(4)
Q1.13.10	Η προσπέραση, αν χρειάζεται	(1)	(2)	(3)	(4)
Q1.13.11	Να παραχωρείτε την προτεραιότητα σας όταν υπάρχει ανάγκη	(1)	(2)	(3)	(4)
Q1.13.12	Να τηρείτε τα όρια ταχύτητας	(1)	(2)	(3)	(4)
Q1.13.13	Να παρκάρετε με την όπισθεν	(1)	(2)	(3)	(4)
Q1.13.14	Να προσέχετε τα άλλα οχήματα στο δρόμο	(1)	(2)	(3)	(4)
Q1.13.15	Να οδηγείτε γρήγορα, αν χρειάζεται	(1)	(2)	(3)	(4)
Q1.13.16	Να οδηγείτε στο σκοτάδι	(1)	(2)	(3)	(4)
Q1.13.17	Να προσέχετε τους πεζούς και τους ποδηλάτες	(1)	(2)	(3)	(4)

14. Πως θα αξιολογούσατε την οδήγησή σας σήμερα σε σχέση με πέντε χρόνια πριν (κυκλώστε)**;**

Q1.14	Χειρότερη (1)	Λίγο χειρότερη (2)	Ίδια (3)	Λίγο καλύτερη (4)	Καλύτερη (5)	Δεν ξέρω (6)

15, 16, 17. Πιο συγκεκριμένα, πως θα αξιολογούσατε την οδήγησή σας στις παρακάτω συνθήκες:

		15. Σε σχέση με 5 χρόνια πριν:			16. Το αποφεύγετε;				17. Αν το αποφεύγετε, για ποιό λόγο γίνεται αυτό; (Αν δεν το αποφεύγετε μην συμπληρώσετε)		
	*Σημειώστε με √ το κουτάκι της επιλογής σας	Σημαντική επιδείνωση	Μικρή επιδείνωση	Καμία διαφορά	Πάντα	Συχνά	Μερικές φορές	Ποτέ	Δεν έχετε κάποιο συγκεκριμένο λόγο	Επειδή διστάζετε ή φοβάστε	Επειδή η οικογένειά σας/ οι δικοί σας το αποθαρρύνουν
Q1.15.1 Q1.16.1 Q1.17.1	Ήπια κίνηση – ήσυχος δρόμος	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.2 Q1.16.2 Q1.17.2	Πόλη με μεγάλη κυκλοφορία	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.3 Q1.16.3 Q1.17.3	Δρόμος ταχείας κυκλοφορίας	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.4 Q1.16.4 Q1.17.4	Αυτοκινητόδρομος	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.5 Q1.16.5 Q1.17.5	Νύχτα	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.6 Q1.16.6 Q1.17.6	Έντονη βροχόπτωση	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.7 Q1.16.7 Q1.17.7	Οδήγηση σε βρεγμένο οδόστρωμα	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.8 Q1.16.8 Q1.17.8	Δρόμος με πολλές στροφές	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.9 Q1.16.9 Q1.17.9	Άγνωστη περιοχή	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.10 Q1.16.10 Q1.17.10	Αλλαγή λωρίδας	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.11 Q1.16.11 Q1.17.11	Μεγάλες αποστάσεις (>2 ώρες)	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.12 Q1.16.12 Q1.17.12	Αριστερές στροφές	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.13 Q1.16.13 Q1.17.13	Οδήγηση ενώ είστε κουρασμένος/η	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.14 Q1.16.14 Q1.17.14	Οδήγηση μόνος στο αυτοκίνητο	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.15 Q1.16.15 Q1.17.15	Συζήτηση με συνεπιβάτη	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.16 Q1.16.16 Q1.17.16	Συνομιλία στο κινητό τηλέφωνο	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.17 Q1.16.17 Q1.17.17	Διασταυρώσεις χωρίς σηματοδότες	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.18 Q1.16.18 Q1.17.19	Προσπέραση σε υπεραστικές οδούς δύο λωρίδων κυκλοφορίας	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)

18. Ποια από τα παρακάτω και πόσο συχνά θεωρείτε ότι σας χαρακτηρίζουν στην οδήγηση;

	Σημειώστε με √ το κουτάκι της επιλογής σας	Ποτέ	Σπάνια	Μερικές φορές	Συχνά	Πάντα
Q1.18.1	Δυσκολίες στον επιμερισμό της προσοχής σας σε διάφορες ενέργειες ταυτόχρονα	(1)	(2)	(3)	(4)	(5)
Q1.18.2	Δυσκολίες στην εκτίμηση της απόστασης και της ταχύτητας των άλλων οχημάτων	(1)	(2)	(3)	(4)	(5)
Q1.18.3	Δυσκολίες στην αντίληψη οχημάτων και πεζών που πλησιάζουν ξαφνικά μπροστά σας από πλευρική κατεύθυνση	(1)	(2)	(3)	(4)	(5)
Q1.18.4	Δυσκολίες στην επικέντρωση της προσοχής στα σήματα κυκλοφορίας σε περιβάλλον όπου υπάρχουν και άλλες πινακίδες	(1)	(2)	(3)	(4)	(5)
Q1.18.5	Δυσκολίες συγκέντρωσης και διατήρησης της προσοχής	(1)	(2)	(3)	(4)	(5)
Q1.18.6	Καθυστέρηση αντίδρασης σε περίπτωση αναγκαστικού φρεναρίσματος	(1)	(2)	(3)	(4)	(5)
Q1.18.7	Δυσκολίες στην ευελιξία χεριών, ποδιών και αυχένα	(1)	(2)	(3)	(4)	(5)
Q1.18.8	Μη επαρκής γνώση των κανόνων κυκλοφορίας και των νέων σημάτων κυκλοφορίας	(1)	(2)	(3)	(4)	(5)
Q1.18.9	Δυσκολίες προσαρμογής σε περιπτώσεις που ξαφνικά εμφανίζονται αλλαγές στις κυκλοφοριακές ρυθμίσεις σε μια συνηθισμένη διαδρομή σας	(1)	(2)	(3)	(4)	(5)

Γ. ΟΔΗΓΗΣΗ ΜΕ ΑΠΟΣΠΑΣΗ ΠΡΟΣΟΧΗΣ

19, 20. Όταν οδηγείτε στις παρακάτω συνθήκες θεωρείτε ότι είναι επικίνδυνο να συνομιλείτε με συνεπιβάτη ή να χρησιμοποιείτε κινητό τηλέφωνο;

		19. Συνομιλία με συνεπιβάτη				20. Χρήση κινητού τηλεφώνου			
	Σημειώστε με √ το κουτάκι της επιλογής σας	Καθόλου επικίνδυνο	Λίγο επικίνδυνο	Αρκετά επικίνδυνο	Πολύ επικίνδυνο	Καθόλου επικίνδυνο	Λίγο επικίνδυνο	Αρκετά επικίνδυνο	Πολύ επικίνδυνο
Q1.19.1 Q1.20.1	**Εντός** πόλης - με **μεγάλη** κυκλοφορία	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Q1.19.2 Q1.20.2	**Εντός** πόλης - με **μικρή** κυκλοφορία	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Q1.19.3 Q1.20.3	**Εκτός** πόλης - με **μεγάλη** κυκλοφορία	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Q1.19.4 Q1.20.4	**Εκτός** πόλης - με **μικρή** κυκλοφορία	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)

21. Τον τελευταίο μήνα πόσο συχνά συνομιλείτε με κάποιον συνεπιβάτη κατά την οδήγηση (κυκλώστε);

Q1.21	Ποτέ (1)	Σπάνια (2)	Μερικές φορές (3)	Πολλές φορές (4)

22. Τον τελευταίο μήνα πόσο συχνά χρησιμοποιείτε κινητό τηλέφωνο κατά την οδήγηση (κυκλώστε);

Q1.22	Ποτέ (1)	Σπάνια (2)	Μερικές φορές (3)	Πολλές φορές (4)

23. Με ποιόν τρόπο και πόσο συχνά αλλάζετε την οδηγική σας συμπεριφορά όταν συνομιλείτε με συνεπιβάτη κατά την οδήγηση;

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	Ποτέ	Σπάνια	Μερικές φορές	Συχνά	Πάντα
Q1.23.1	Μειώνω ταχύτητα και οδηγώ πιο προσεκτικά	(1)	(2)	(3)	(4)	(5)
Q1.23.2	Προσπαθώ να έχω μεγαλύτερη απόσταση από το προπορευόμενο όχημα	(1)	(2)	(3)	(4)	(5)
Q1.23.3	Οδηγώ πιο δεξιά, επί του οδοστρώματος	(1)	(2)	(3)	(4)	(5)
Q1.23.4	Συμπληρώστε κάποιον άλλον τρόπο αλλαγής της οδηγικής σας συμπεριφοράς____________	(1)	(2)	(3)	(4)	(5)

24. Με ποιόν τρόπο και πόσο συχνά αλλάζετε την οδηγική σας συμπεριφορά όταν κάνετε χρήση κινητού τηλεφώνου κατά την οδήγηση; (αν δεν χρησιμοποιείτε κινητό τηλέφωνο κατά την οδήγηση περάστε στην ερώτηση 25)

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	Ποτέ	Σπάνια	Μερικές φορές	Συχνά	Πάντα
Q1.24.1	Μειώνω ταχύτητα και οδηγώ πιο προσεκτικά	(1)	(2)	(3)	(4)	(5)
Q1.24.2	Σταματάω το όχημα σε ασφαλές σημείο	(1)	(2)	(3)	(4)	(5)
Q1.24.3	Προσπαθώ να έχω μεγαλύτερη απόσταση από το προπορευόμενο όχημα	(1)	(2)	(3)	(4)	(5)
Q1.24.4	Οδηγώ πιο δεξιά, επί του οδοστρώματος	(1)	(2)	(3)	(4)	(5)
Q1.24.5	Συμπληρώστε κάποιον άλλον τρόπο αλλαγής της οδηγικής σας συμπεριφοράς____________	(1)	(2)	(3)	(4)	(5)

Δ. ΣΥΝΑΙΣΘΗΜΑΤΑ ΚΑΙ ΣΥΜΠΕΡΙΦΟΡΑ ΟΔΗΓΟΥ

25. Πόσες φορές τον τελευταίο χρόνο βιώσατε ένα διαπληκτισμό με συνεπιβάτη σας καθώς οδηγούσατε (κυκλώστε);

Q1.25	0	1	2	3	4	5	6	7	8	9+

26. Πόσες φορές τον τελευταίο χρόνο βιώσατε ένα διαπληκτισμό με οδηγό άλλου οχήματος (κυκλώστε);

Q1.26	0	1	2	3	4	5	6	7	8	9+

27. Πόσες φορές τον τελευταίο χρόνο «ήρθατε στα χέρια» με οδηγό άλλου οχήματος (κυκλώστε);

Q1.27	0	1	2	3	4	5	6	7	8	9+

28. Χρησιμοποιείτε τη ζώνη ασφαλείας (κυκλώστε);

Q1.28	Καθόλου (1)	Σπάνια (2)	Μερικές φορές (3)	Πολύ συχνά (4)	Πάντοτε (5)

29. Οδηγείτε υπό την επήρεια αλκοόλ όταν είστε έξω με τους φίλους σας (κυκλώστε);

Q1.29	Καθόλου (1)	Σπάνια (2)	Μερικές φορές (3)	Πολύ συχνά (4)

30. Οδηγείτε επικίνδυνα για εσάς και τους άλλους όταν είστε έξω με τους φίλους σας (κυκλώστε)**;**	Q1.30	Καθόλου (1)	Σπάνια (2)	Μερικές φορές (3)	Πολύ συχνά (4)

31. Σε γενικές γραμμές πόσο συχνά οδηγείτε χωρίς να είστε συγκεντρωμένος-η (κυκλώστε)**;**	Q1.31	Καθόλου (1)	Σπάνια (2)	Μερικές φορές (3)	Πολύ συχνά (4)

Ε. ΚΛΙΜΑΚΑ ΕΚΦΡΑΣΗΣ ΘΥΜΟΥ ΚΑΤΑ ΤΗΝ ΟΔΗΓΗΣΗ

32. Πόσο συχνά συμβαίνουν τα παρακάτω γεγονότα, καθώς οδηγείτε;

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	Σχεδόν ποτέ	Σπάνια	Συχνά	Σχεδόν πάντα
Q1.32.1	Φωνάζω επικριτικά σχόλια, όπως «Νύχτα πήρες το δίπλωμα;»	(1)	(2)	(3)	(4)
Q1.32.2	Βρίζω τον άλλο οδηγό δυνατά	(1)	(2)	(3)	(4)
Q1.32.3	Βρίζω τον άλλο οδηγό χαμηλόφωνα	(1)	(2)	(3)	(4)
Q1.32.4	Αγριοκοιτάζω τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.5	Κουνάω το κεφάλι μου αποδοκιμαστικά στον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.6	Σκέφτομαι πράγματα όπως «Νύχτα πήρες το δίπλωμα;»	(1)	(2)	(3)	(4)
Q1.32.7	Προσπαθώ να βγω από το αυτοκίνητο και να βρίσω τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.8	Προσπαθώ να εξωθήσω τον άλλο οδηγό στη άκρη του δρόμου	(1)	(2)	(3)	(4)
Q1.32.9	Κάνω άσεμνες χειρονομίες με το χέρι στον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.10	Προσπαθώ να τρομάξω τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.11	Παθαίνω κρίση πίσω από το τιμόνι	(1)	(2)	(3)	(4)
Q1.32.12	Μουντζώνω τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.13	Οδηγώ κατευθείαν στον προφυλακτήρα του άλλου οδηγού	(1)	(2)	(3)	(4)
Q1.32.14	Προσπαθώ να βρεθώ μπροστά από τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.15	Ακολουθώ τον άλλο οδηγό ακριβώς από πίσω του για πολλή ώρα	(1)	(2)	(3)	(4)
Q1.32.16	Αναβοσβήνω τα φώτα μου στον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.17	Επίτηδες εμποδίζω τον άλλο οδηγό να πάει εκεί που θέλει	(1)	(2)	(3)	(4)
Q1.32.18	Κάνω στους άλλους οδηγούς ό,τι έκαναν σε μένα	(1)	(2)	(3)	(4)
Q1.32.19	Οδηγώ ταχύτερα απ' ό,τι πριν	(1)	(2)	(3)	(4)
Q1.32.20	Επιβραδύνω για να εκνευρίζω τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.21	Αφήνω τα μεγάλα φώτα να φωτίζουν στον καθρέφτη του άλλου οδηγού	(1)	(2)	(3)	(4)
Q1.32.22	Ξεσπάω τον θυμό μου στους συνεπιβάτες μου	(1)	(2)	(3)	(4)
Q1.32.23	Δεν μπορώ να ηρεμήσω και παραμένω θυμωμένος /η όλη την ώρα	(1)	(2)	(3)	(4)
Q1.32.24	Εκτονώνω τον θυμό μου σε άλλους αργότερα	(1)	(2)	(3)	(4)
Q1.32.25	Σκέφτομαι πρώτα προτού αντιδράσω	(1)	(2)	(3)	(4)
Q1.32.26	Προσπαθώ να σκεφτώ θετικές λύσεις για να αντιμετωπίσω την κατάσταση	(1)	(2)	(3)	(4)
Q1.32.27	Δίνω ακόμα περισσότερη προσοχή στο δρόμο, προς αποφυγή ατυχημάτων	(1)	(2)	(3)	(4)
Q1.32.28	Αποφασίζω να μην πέσω στο επίπεδό τους	(1)	(2)	(3)	(4)
Q1.32.29	Λέω στον εαυτό μου ότι δεν αξίζει να εμπλακώ	(1)	(2)	(3)	(4)
Q1.32.30	Απλά προσπαθώ να αποδεχτώ ότι υπάρχουν και κακοί οδηγοί στον δρόμο	(1)	(2)	(3)	(4)

	*Σημειώστε με √ το κουτάκι της επιλογής σας	**Σχεδόν ποτέ**	**Σπάνια**	**Συχνά**	**Σχεδόν πάντα**
Q1.32.31	Απλά προσπαθώ να αποδεχτώ ότι υπάρχουν καταστάσεις που προκαλούν εκνευρισμό	(1)	(2)	(3)	(4)
Q1.32.32	Ανοίγω το ραδιόφωνο ή βάζω μουσική για να ηρεμήσω	(1)	(2)	(3)	(4)
Q1.32.33	Κάνω πράγματα όπως βαθιές αναπνοές για να ηρεμήσω	(1)	(2)	(3)	(4)
Q1.32.34	Σκέφτομαι πράγματα που με αποσπούν από τον εκνευρισμό στον δρόμο	(1)	(2)	(3)	(4)

ΣΤ. ΙΣΤΟΡΙΚΟ ΣΥΜΒΑΝΤΩΝ

33. Πόσα ατυχήματα συνολικά είχατε ως οδηγός (κυκλώστε);

Q1.33	0	1	2	3	4	5	6	7	8	9+

34. Πόσες φορές τα τελευταία δύο χρόνια, αποφύγατε «την τελευταία στιγμή» ένα ατύχημα (κυκλώστε);

Q1.34	0	1	2	3	4	5	6	7	8	9+

35. Πόσα ατυχήματα μόνο με υλικές ζημιές είχατε τα τελευταία δύο χρόνια με το αυτοκίνητο(κυκλώστε);

Q1.35	0	1	2	3	4	5	6	7	8	9+

36. Πόσα σοβαρά ατυχήματα με τραυματισμό είχατε τα τελευταία δύο χρόνια με το αυτοκίνητο(κυκλώστε);

Q1.36	0	1	2	3	4	5	6	7	8	9+

37. Πόσες φορές τα τελευταία δύο χρόνια, παραβιάσατε τον Κώδικα Οδικής Κυκλοφορίας ενώ οδηγούσατε (κυκλώστε);

Q1.37	0	1	2	3	4	5	6	7	8	9+

38. Τα τελευταία δύο χρόνια, πόσες κλήσεις είχατε για παραβάσεις του Κώδικα Οδικής Κυκλοφορίας (κυκλώστε);

Q1.38	0	1	2	3	4	5	6	7	8	9+

Annex 3: Self-Assessment and Memory Questionnaire

Α/Α Συμμετέχοντα:		
Ημερομηνία πειράματος:		
Ηλικία:		
Φύλο (κυκλώστε)**:**	Άντρας (1)	Γυναίκα (2)

Α. ΕΡΩΤΗΣΕΙΣ ΑΝΑΚΛΗΣΗΣ

1. Ποιο ήταν το όριο ταχύτητας στον εξοχικό δρόμο (συμπληρώστε)**;**

Q3.1	

2. Ποιο είδος ζώου ή ζώων διέσχισαν το δρόμο στον εξοχικό δρόμο (συμπληρώστε)**;**

Q3.2	

3. Πόσες λωρίδες είχε η κάθε κατεύθυνση στον εξοχικό δρόμο (συμπληρώστε)**;**

Q3.3	

4. Ποιο ήταν το όριο ταχύτητας στην πόλη (συμπληρώστε)**;**

Q3.4	

5. Ποιο ήταν το χρώμα της μπάλας που διέσχισε το δρόμο μαζί με ένα παιδάκι στην πόλη (συμπληρώστε)**;**

Q3.5	

6. Ποιο είδος ζώου φαινόταν σε ταμπέλα σήμανσης στον εξοχικό δρόμο (προσοχή ζώα); (συμπληρώστε)**;**

Q3.6	

7. Ποιος ήταν ο μέγιστος αριθμός λωρίδων που συναντήσατε μέσα στην πόλη και στον εξοχικό δρόμο (συμπληρώστε)**;**

Q3.7	

8. Τι υπήρχε μέσα στη λίμνη στον εξοχικό δρόμο (συμπληρώστε)**;**

Q3.8	

Β. ΕΡΩΤΗΣΕΙΣ ΑΝΑΓΝΩΡΙΣΗΣ

9. Ποιο ήταν το όριο ταχύτητας στον εξοχικό δρόμο (κυκλώστε);

Q3.09	**50**	**70**	**90**

10. Ποιο είδος ζώου ή ζώων διέσχισαν το δρόμο στον εξοχικό δρόμο (κυκλώστε);

Q3.10	**Αγελάδα**	**Ελάφι**	**Γαϊδούρι**

11. Πόσες λωρίδες είχε στον εξοχικό δρόμο η κάθε κατεύθυνση στον εξοχικό δρόμο (κυκλώστε);

Q2.11	**1**	**2**	**3**

12. Ποιο ήταν το όριο ταχύτητας στην πόλη (κυκλώστε);

Q3.12	**40**	**50**	**60**

13. Ποιο ήταν το χρώμα της μπάλας που διέσχισε το δρόμο μαζί με ένα παιδάκι στην πόλη (κυκλώστε);

Q2.13	**Κόκκινο - Πορτοκαλί**	**Μπλέ**	**Πράσινο**

14. Ποιο είδος ζώου απεικονιζόταν σε ταμπέλα σήμανσης στον εξοχικό δρόμο; (κυκλώστε);

Q3.14	**Αγελάδα**	**Ελάφι**	**Κατσίκα**

15. Ποιος ήταν ο μέγιστος αριθμός λωρίδων που συναντήσατε μέσα στην πόλη και στον εξοχικό δρόμο (κυκλώστε);

Q3.15	**1**	**2**	**3**

16. Τι υπήρχε μέσα στη λίμνη στον εξοχικό δρόμο (κυκλώστε);

Q3.16	**Μεγάλο πλοίο**	**Καϊκάκι - Ιστιοπλοϊκό**	**Μικρή σχεδία**

Γ. ΕΡΩΤΗΣΕΙΣ ΑΥΤΟΑΞΙΟΛΟΓΗΣΗΣ

17. Σήμερα στον προσομοιωτή η ταχύτητά μου ήταν:

	Σημειώστε με √ το κουτάκι της επιλογής σας	Αργή	Κανονική	Γρήγορη
Q3.17.1	Εντός κατοικημένης περιοχής	(1)	(2)	(3)
Q3.17.2	Εκτός κατοικημένης περιοχής	(1)	(2)	(3)

18. Σήμερα στον προσομοιωτή οι αποστάσεις που κρατούσα από τα προπορευόμενα οχήματα ήταν:

	Σημειώστε με √ το κουτάκι της επιλογής σας	Μικρές	Κανονικές	Μεγάλες
Q3.18.1	Εντός κατοικημένης περιοχής	(1)	(2)	(3)
Q3.18.2	Εκτός κατοικημένης περιοχής	(1)	(2)	(3)

19. Σήμερα στον προσομοιωτή η θέση μου στη λωρίδα ήταν:

	Σημειώστε με √ το κουτάκι της επιλογής σας	Πιο κοντά στη μέση	Στο κέντρο	Πιο κοντά στην άκρη
Q3.19.1	Εντός κατοικημένης περιοχής	(1)	(2)	(3)
Q3.19.2	Εκτός κατοικημένης περιοχής	(1)	(2)	(3)

20. Σήμερα στον προσομοιωτή οι αντιδράσεις μου στα συμβάντα ήταν:

	Σημειώστε με √ το κουτάκι της επιλογής σας	Αργές	Κανονικές	Γρήγορες
Q3.20.1	Εντός κατοικημένης περιοχής	(1)	(2)	(3)
Q3.20.2	Εκτός κατοικημένης περιοχής	(1)	(2)	(3)

21. Σήμερα στον προσομοιωτή ζαλιστήκατε κατά τη διάρκεια της οδήγησης;

	Σημειώστε με √ το κουτάκι της επιλογής σας	Καθόλου	Ελαφρά	Μέτρια	Πολύ
Q3.21.1	Εντός κατοικημένης περιοχής	(1)	(2)	(3)	(4)
Q3.21.2	Εκτός κατοικημένης περιοχής	(1)	(2)	(3)	(4)