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Doctoral dissertation

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EVALUATION AND MITIGATION OF THE RISK OF ROAD ACCIDENT IN URBAN AREAS ACCORDING TO TECHNIQUES BASED ON HUMAN-ROAD INTERACTION

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1. INTRODUCTION

1.1 The global burden of road traffic deaths

Deaths and injuries resulting from road traffic crashes is a serious problem globally and current trends suggest that this will continue to be the case in the foreseeable future [1]. The number of road traffic deaths continues to climb, reaching a high of 1.35 million in 2016 [2]. That's nearly 3 700 people dying on the world's roads every day. However, the rate of death relative to the size of the world's population has stabilized and declined relative to the number of motor vehicle in recent years [3]. As shown in Figure 1.1, despite the increase in absolute numbers, the rate of road traffic deaths has remained fairly constant at around 18 deaths per 100.000 population over the last 15 years. While this does suggest that the problem is not worsening, as we approach the end of the Decade of Action for Road Safety 2011-2020 the world is far from achieving SDG target 3.6, which calls for a reduction of road traffic deaths by 50% by 2020 [4].

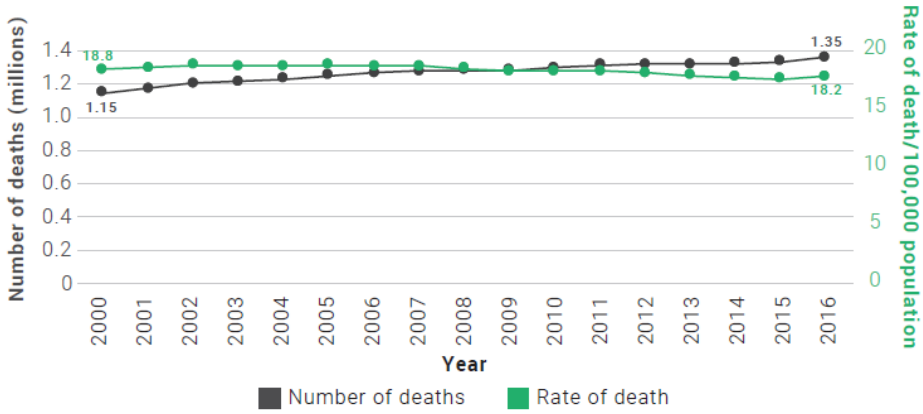

Figure 1.1 Number and rate of road traffic death in the world per 100.000 population: 2000-2016 [2].

While progress has been made by countries in strengthening road traffic laws, improving the safety of roads and vehicles, and enhancing post-crash care, the number of road traffic deaths and injuries on the world's roads remains unacceptably high. Road traffic injury is indeed the 8th leading cause of death for all age groups, and it is also the leading cause of death for children and young adults aged 5-29 years, signalling a need for a shift in the current child health agenda, which has largely neglected the road safety [5]. As progress is made in the prevention and control of infectious diseases, the relative contribution of deaths from noncommunicable diseases and injuries increases [4, 5]. More people now die as a result of road traffic injuries than from HIV/AIDS, tuberculosis and diarrhoeal diseases [5]. It has also to be considered that, in addition to the injuries and disabilities resulting from road traffic crashes, the safety of roads (or lack thereof) also impacts other public health issues as it contributes to inactivity. People are less likely to walk, cycle, or use public transportation when conditions are unsafe [6].

Of all the systems that people have to deal with on a daily basis, road transport is the most complex and the most dangerous. Worldwide, the number of people injured in road traffic crashes could be as high as 50 million – the combined population of five of the world's large cities [2]. The tragedy behind these figures regularly attracts less media attention than other, less frequent but more unusual types of tragedy.

As for European Union, 25,047 people lost their lives on EU roads in 2018, representing a 1% reduction compared to 2017 [7]. The EU has collectively reduced the number of road deaths by just 4% over the last five years. There has been progress over a longer period, but not enough to meet the 2020 target. Since 2010, EU countries achieved an overall reduction in road deaths of 20.7% (Figure 1.2), which equals a 2.8% annual average reduction. A 6.7% year-to-year reduction was needed over the 2010-2020 period to reach the 2020 target through constant progress in annual percentage terms. This reduction was not achieved and the target is now effectively out of reach [7]. The EU would need to reduce the number of road deaths by 20.6% in 2019 and 2020 to reach the target - a highly unlikely possibility.

With regard to Italy, 172,344 road accidents occurred in 2018 resulting in death or injury, down comparing with 2017 (-1.5%), with 3,325 deaths (within 30 days) and 242,621 injured (-1.7%).

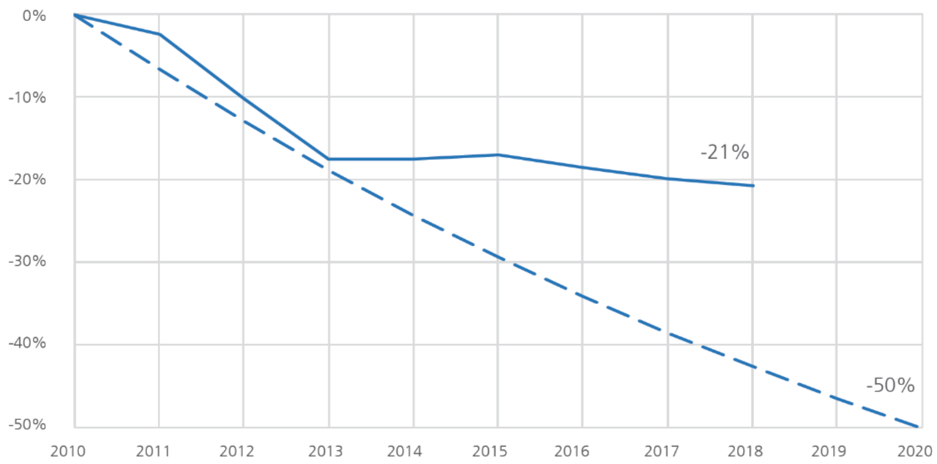

Figure 1.2 – Reduction in the number of road deaths in the EU since 2010 (blue line) plotted against the target for 2020 (blue dotted line) [8].

1.2 The problem of road safety and crashes in urban areas

Of the total 1.35 million people dying in road traffic crashes annually, at least 30% are in urban areas (WHO 2018). Although all types of road user are at risk of being injured or killed in a road traffic crash, there are notable differences in fatality rates between different road user groups. In particular, the “vulnerable” road users such as pedestrians and two-wheeler users are at greater risk than vehicle occupants and usually bear the greatest burden of injury [2]. Almost half of all deaths on the world’s roads are among those with the least protection– motorcyclists (23%), pedestrians (22%) and cyclists (4%) [2]. This is especially true in low-income and middle-income countries, because of the greater variety and intensity of traffic mix and the lack of separation from other road users. By contrast, in high-income countries car occupants represent more than 60% of all fatalities, a reflection of the greater number of motor vehicles in use. While there are fewer motorcyclist, cyclist and pedestrian casualties, these groups of road users bear higher fatality rates [8]. Although pedestrians, cyclists and riders of motorized two-wheelers are more vulnerable as a result of being less protected than car occupants, the heavy burden of deaths borne by these road users is also a reflection of infrastructure and vehicle design that prioritizes cars and other motorized transport. Therefore urban traffic safety requires special focus on making the urban environment safer for pedestrians, bicyclists and motorcycle users.

With regards to EU, 9500 people were killed on urban roads in the EU in 2017, accounting for 38% of all road deaths [9]. Road deaths on urban roads in the EU have decreased by 14% since 2010, compared to reductions of 16% on motorways and 24% on rural roads (Figure 1.3). Road deaths on urban roads decreased on average by 2.2% each year between 2010 and 2017, compared to 3.9% on rural roads, i.e. an average difference of 1.7 percentage points. Over 100,000 people were seriously injured on urban roads in the EU in 2017, accounting for over 50% of all serious road traffic injuries.

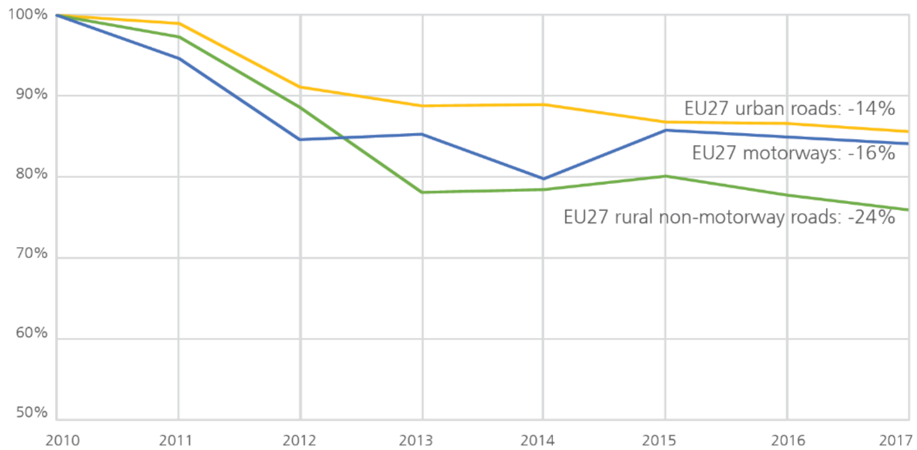

Figure 1.3 - Progress in reducing in the number of reported road deaths on urban roads, rural non-motorway roads and motorways in 27 EU countries for which data are available [27].

In the EU, 70% of all road users killed on urban roads are vulnerable road users: 39% are pedestrians, 12% cyclists and 19% powered-two-wheeler riders. Car occupants account for 25% of all roads deaths on urban roads (Figure 1.4). For comparison, vulnerable road users account for 34% of all road deaths on rural non-motorway roads: 10% are pedestrians, 6% cyclists and 18% powered-two-wheeler riders. Car occupants account for 58% of all road deaths on rural roads (Figure 1.4). These differences are not surprising due to the traffic composition on urban roads, where vulnerable road users frequently and closely interact with motorised vehicles, and on rural roads that are mostly used by motorised vehicles. A substantial body of literature points to the propensity of some road user groups, particularly pedestrians and those using motorized and nonmotorized two-wheelers, to be vastly overrepresented among crash victims at the global level [10] and be at higher risk of crash-related disability [11].

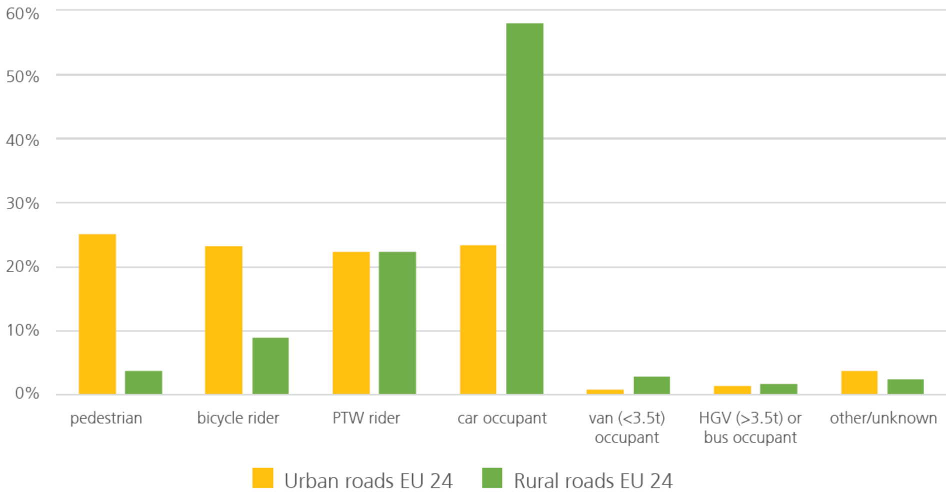

Figure 1.4 - Proportion of reported road deaths by road user group on urban roads and rural-non motorway roads (for comparison) in the EU, average of years 2015-2017 [27].

Increasing evidence suggests that the true impact of road safety in cities goes well beyond the direct suffering due to crashes. For instance, road safety determines the success or failure of the sustainable urban mobility transition, with a range of health benefits at stake, not to mention other social, economic and environmental benefits. Real and perceived safety has a profound effect on modal choice especially in terms of the most sustainable modes of travel - walking and cycling and the ability to access public transport. Cities and towns are home to 72% of the population of the European Union [12]. These are the places where the majority of journeys begin and end [13]. Urban populations are increasing, the population is ageing, people are being encouraged to walk and cycle more as concerns over congestion and air pollution move up the political agenda. New forms of mobility are popping up increasingly. There is widespread evidence that European citizens see road safety in their cities as a problem and in particular they say that traffic safety is a barrier to taking up cycling. A Eurobarometer survey shows that 73% of European citizens consider road safety to be a serious problem in cities [14]. A survey in London showed that 59% of potential cyclists cited safety concerns as a key barrier preventing them from cycling [15]. Traffic safety was also the main barrier to taking up cycling identified in a recent survey undertaken in nine European cities [16]. Almost half of all car trips in urban areas in the EU are over distances shorter than 5 km and many of these can be replaced by walking or cycling [17]. It is important to recognise that safer roads also mean more sustainable roads. If groups of road users are deterred from using unsafe roads, they might shift to other less sustainable modes of transport [9]. Meeting the demands of the most vulnerable road users – the elderly, children and people with reduced mobility – will not only help to achieve the highest safety standards but also help all road users to profit from a much safer urban environment. Modal shift away from private motor vehicles could significantly improve road safety in dense urban areas [18]. Making active travel an attractive and safe alternative to motorised transport will result in decreased traffic noise, CO_2 emissions (and sea level rise), pollution and congestion in urban areas and at the same time improve health and quality of life. Such a policy requires taking road space from motorised traffic and transforming it into space to facilitate walking and cycling.

Despite all this, deaths and serious injuries on urban roads are not declining as fast as on other types of roads. Moreover, deaths of vulnerable road users are not declining as fast as those of motor vehicle occupants. In urban centres, the statistics are stark, 70% of reported road deaths are pedestrians, cyclists and power-two-wheeler riders. New measures are needed urgently as the progress in reducing serious road traffic injuries on urban roads has largely stalled since the beginning of the decade.

1.3 Human factor and road crashes

Because of the enormous losses to society that are caused by crashes, and the need for implementing evidence-based road safety policies and measures to reduce the number of crashes, researchers continuously aim to gain a deeper understanding of factors that affect the occurrence and severity of crashes [19]. It is commonly acknowledged that road environment are integrated in the transport system with two main interfaces between the road users on one hand and the vehicles on the other (Figure 1.5).

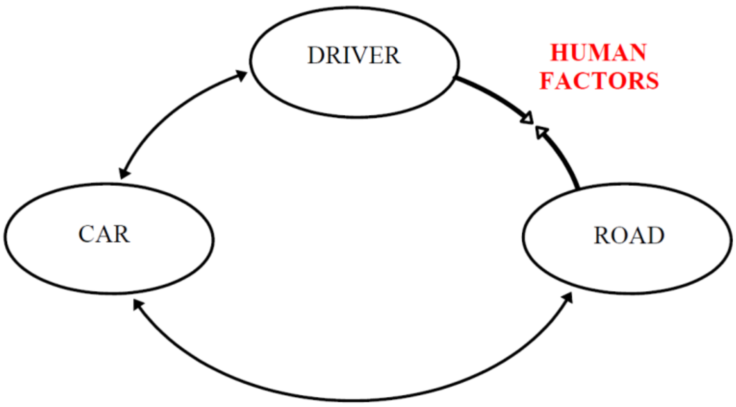

Figure 1.5 - The main interfaces of the road transport system.

It is widely recognized that human factors may contribute to accident involvement in traffic [36]. From an engineering as well as road accident administration point of view it is generally accepted that in the interaction of the vehicle, infrastructure and driver, the driver related factors were solely to blame for around 50% of accidents and the Human Factors are somehow involved in the occurrence of accidents in over 90% of the cases [20]. Based on a study of 2041 traffic accidents, Sabey and Taylor [21] concluded that human factors were contributing elements in more than 90% of the accidents. In particular, driving behaviour was identified as the most central of these factors. Driving attitude, which is manifested by driving behaviour, strongly affect the hazard perception of drivers [22]. It is therefore important to understand the various aspects that affect the drivers' ability. Figure 1.6 shows the distribution of how the three factors human, vehicle and (road) environment contribute to the occurrence of road traffic accidents. The overlapping areas indicate the interaction of the three factors.

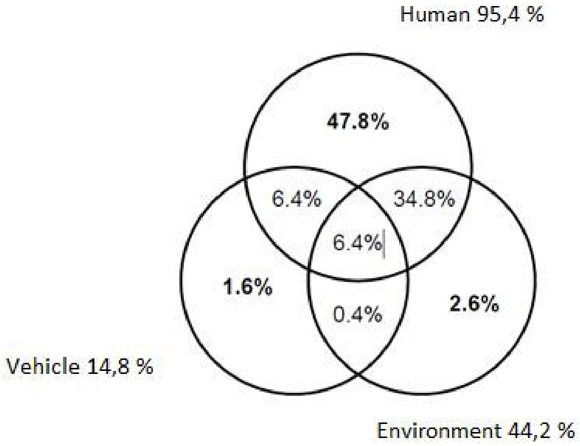

Figure 1.6 - Distribution of how the three factors human, vehicle and (road) environment contribute to the occurrence of road traffic accidents [35].

The term Human Factor means a number of psychological and physiological threshold limit values and activity patterns in operating machines, cars and other technical facilities [23]. Human Factors are typical limitations of the perception system, information processing, learning or decision making of all human beings. Human Factors are defined as stable, general human abilities and limitations that are valid for all users regardless of age, culture or race. Temporary effects or circumstances like illness, alcohol, fear, aggression or traffic violation are not considered as Human Factors [24]. They are considered as conscious behavioural factors and should be treated by enforcement, education or public awareness campaigns.

The traditional view in road safety has been that when crashes occur, they are usually the sole responsibility of individual road users, despite the fact that other factors beyond their control may have come into play, such as the poor design of roads or vehicles. It is still widely held today that since human error is a factor in some 90% of road crashes, the leading response should be to persuade road users to adopt “error-free” behaviour. According to this policy, information and publicity should form the backbone of road traffic injury prevention, rather than being one element of a much more comprehensive programme [25, 26].

Human error on the roads does not always lead to disastrous consequences. Accidents are the result of a long chain of events starting with an operational mistake and – if not corrected – leading to a driving mistake and – under bad circumstances – to an accident. Error by a road user, though, may indeed trigger a crash, but not necessarily be its underlying cause. In addition, human behaviour is governed not only by individual knowledge and skills, but also by the environment in which the behaviour takes place [27, 28]. Indirect influences, such as the design and layout of the road, the nature of the vehicle, and traffic laws and their enforcement or lack of enforcement, affect behaviour in important ways. Road safety depends on the integrated and complex relationship between various components: the driver's psychology, the traffic, the vehicle, the environment and the road infrastructure. The human element is certainly the most vulnerable, but also the most flexible, in any decision-making process. Road users try to drive in a safe way but the task is complex and the environment is not designed to prevent errors occurring. Indirect influences, such as the design and layout of the road, the nature of the vehicle, and traffic laws and their enforcement – or lack of enforcement – affect behaviour in important ways. For this reason, the use of information and publicity on their own is generally unsuccessful in reducing road traffic collisions [29, 30, 31]. Error is part of the human condition. Aspects of human behaviour in the context of road traffic safety can certainly be altered. Nonetheless, errors can also be effectively reduced by changing the immediate environment rather than focusing solely on changing the human condition [32]. One cannot hope to fight human error effectively without and understanding of the processes that err, and of the conditions that invite such errors [33]. The inappropriate design of the road infrastructure neglecting the road user limitations will result in latent risks that trigger operational mistakes and accidents.

Error is part of the human condition. Aspects of human behaviour in the context of road traffic safety can certainly be altered. Nonetheless, errors can also be effectively reduced by changing the immediate environment, rather than focusing solely on changing the human condition [34]. The road traffic system needs to ensure, through its design and operation, that it does not lead to significant public health loss [35]. A human-centred design and an integrated road traffic system taking the human capabilities and limitations into account can minimize both the occurrence and consequences of the human error [36]. The uncertainty of human behaviour in a complex traffic environment means that it is unrealistic to expect that all crashes can be prevented. However, if greater attention in designing the transport system were given to the tolerance of the human body to injury, there could be substantial benefits. It is certainly within the bounds of possibility to try to ensure that if crashes do occur, they do not, as a matter of course, lead to serious public health loss.

Comply with key safety rules and avoid dangerous situations is of course a strict obligation for each road user [37]. However, in order to achieve a safe transport system, there must be a change in our views concerning responsibility, to the extent that system designers are given clearly defined responsibility for designing the road system on the basis of actual human capabilities, thereby preventing the occurrence of those cases of death and serious injury that are possible to predict and prevent [38].

Road traffic crashes are predictable and can be prevented in several situations. This can be achieved by adopting a systems approach to road safety that emphasizes environment, vehicle and road user interventions, rather than solely focusing on direct approaches aimed at changing the behaviour of road users [25]. Since human error in complex traffic systems cannot be eliminated entirely, environmental solutions (including the design of roads and of vehicles) must help in making road traffic systems safer. Making a road traffic system less hazardous requires a “systems approach” – understanding the system as a whole and the interaction between its elements, and identifying where there is potential for intervention. In particular, it requires recognition that humans make mistakes. A safe road traffic system is one that accommodates and compensates for human fallibility [39].

Considering the extreme complexity of urban areas and of human factor, the aspects influencing the road safety should be studied with specific regard to specific categories of road users and to some elements of road networks. The safety perception of road infrastructure in any urban context is indeed a cognitive process that can result in significantly different actions and behaviours depending on the type of users and on the type of road element. Road users are different for age, gender, social extraction, cultural level, driving experience, familiarity with different means of transport, etc. A child, for example, is an "actor" of urban mobility exclusively as a pedestrian or cyclist and has a radically different road experience from a professional bus driver. And yet both of them coexist in the same urban environment. Similar considerations can be done for other road users. Because of this, in order to improve road safety in urban areas it is necessary to evaluate the safety perception and the driving behaviour for different categories of users (e.g. male and female, young people, old people, children, drivers, bicyclists, pedestrian, etc.) and in specific elements of road networks (e.g. intersections, roundabouts, home-school paths etc.).

1.4 Techniques for exploring human-road interaction

To better understand the influence of human factor in driving behaviour and in road safety perception different methods can be used. The classical approach is the epidemiological approach which attempt to understand the causes of road traffic injuries, to determine the correlations between causes of road crash injury, to determine the factors that could increase or decrease the risk of road traffic injuries and to determine the factors that might be modifiable through interventions [40]. Apart from the classical approach based on the analysis of road traffic injuries, other techniques using different input data can be adopted to explore human-road interaction. The following subparagraphs briefly describes these techniques.

1.4.1 Self-reports methods

The first option is represented by self-reports. Self-reports include a great variety of different methods, including questionnaires and inventories, interviews, focus groups [41, 42], and driving diaries [43, 44, 45]. Because social psychological studies are mostly based on self-reports, increased interest in social psychological factors has also resulted in the increased use of self-report methodology [46]. Common features in all these diverse self-report measures are that participants are aware that they are participating in a study; they are asked to actively reply to more or less structured questions; and their responses are taken as “face valid” that is, answers are scored and analysed based on the responses and not, for example, according to response time or other behavioural or physiological measurement. In self-reports, the content of the responses in this way is assumed to reflect a respondent’s reality. Self-reports and especially questionnaires have many advantages. They are usually less expensive than studies using an instrumented vehicle or a simulator, they provide more detailed information than observations, and they can reach large numbers of people [46]. Representativeness of the sample is easy to establish and can be measured with direct statistical comparisons to driver populations. Moreover, the reliability of items and measurements can be easily evaluated with standard statistics. Due to large samples, complicated and detailed statistical analyses can be conducted. Although self-reports can offer a rich source of information, they also have some serious shortcomings and limitation that have to be taken into account. As stated by Reason et al. [47] self-reports are powerful mean to measure behaviours that are “too private to be detected by direct observation” but that at the same time “responses are several stages removed from the actuality of what goes on behind the wheel”. The gap mentioned by Reason et al. between the reality and the picture given by self-reports may not be possible to erase, but at least it can be considerably reduced with adequate use of self-report methodology [46].

1.4.2 Naturalistic observations

Naturalistic observation takes place in the setting in which the behaviour of interest occurs. In terms of traffic psychology, this setting consists of the roadway network and the vehicle occupants who travel on these roadways. The research method of naturalistic observation involves a researcher (or, more commonly, several researchers) making careful observations about what he or she sees on the roadways. These observations can occur as the behaviour is happening, or the behaviour can be video recorded and observed at a later time. There are two main strengths of this method. The first is that it taps directly into the behaviour of interest and does not rely on having to interpret proxies of behaviours such as self-reports. Second, because the behaviours observed occur in natural settings, naturalistic observation has strong construct and face validity; that is, it very likely represents reality, an argument that is more difficult to make with other research methods, such as a driving simulator. On the other hand, naturalistic observation as a research method has some drawbacks. The main disadvantage is generalizability. Because the observed behaviours are only a sample of all of the behaviours that occur, it is difficult to conclude that the observed behaviours would also occur for other people who have not been observed. Although a good sampling design can minimize this issue, it cannot be eliminated [46]. Another limitation is that the technique involves observers (data collectors) who may have biases that affect what they see and record. Such observer bias, however, can be diminished through training or video recordings. Finally, naturalistic observational methods can be labour-intensive and, therefore, costly. Naturalistic observation was one of the earliest research methods used in traffic safety research. Indeed, based on naturalistic observation of driver behaviour nearly a century ago, Dodge [48] argued for a systematic exploration of human behaviour in traffic to improve safety. Naturalistic observation has been used extensively in the past century, and it is still commonly used today [49, 50, 51, 52].

Naturalistic observation can be direct or unobtrusive. Direct observation means researchers standing along roadways, or in some other location that is accessible to traffic, looking into vehicles and recording what they see. The researchers are clearly visible to vehicle occupants. Because direct observation allows for the vehicle occupants to see the researchers and know they are being observed, occupants may change the behaviour of interest. In contrast, unobtrusive observation involves efforts to conceal the researchers from the vehicle occupants. Concealment can mean physically hiding the researchers as they collect data along the roadway or, more commonly, using camera or video technology that can be placed in inconspicuous locations [53, 54, 55, 56, 57].

1.4.3 Driving studies

Technological improvements have enabled traffic safety researchers to better study driver behaviour in situ or in real-world traffic environments. Improvements in computer processing speed and data storage coupled with the reduction in physical size of these components have not only allowed instrumented vehicle studies to gather more parametric data but also resulted in vast improvements in video data collection. These improvements have allowed safety professionals to retrofit vehicles with eye tracking systems, physiological monitoring equipment, and collision warning systems. Advances in technology have expanded the capabilities of observation by allowing vehicles to be equipped with tiny video cameras and other sensors, known as instrumented vehicle research [58, 59, 60, 61].

Driving studies range from one vehicle for a 30-min test period (*controlled driving studies*) to driving simulator studies to large-scale deployment of instrumented vehicles with data collected over a long period of time (*naturalistic driving studies*).

In *controlled driving studies* subjects drive in real traffic with, usually, an experimenter on-board. This makes subjects aware of the fact that they participate in an experiment which may affect their driving behaviour. Instrumented vehicles are often used for *controlled driving studies*. An instrumented vehicle permits quantitative assessments of driver performance in the field, under actual road conditions. Instrumented vehicles for *controlled driving studies* are usually equipped with cameras and sensors which allowed to record vehicle manoeuvres (such as speed, acceleration/deceleration, direction), driver behaviour (such as eye, head and hand movements), and external conditions (such as road, traffic and weather characteristics).

The greatest incentive for *driving simulator studies* is the ability to control the experience of the participants and to create repeatable situations, scenes, and scenarios. Simulators can vary from simple facsimiles of driving using a joystick control with a simplified road environment displayed on a PC screen to multi-million-dollar laboratories providing full-size vehicles mounted on motion systems with up to 9 degrees of freedom and a field of view of up to 360° [62]. The possibility of control of driving simulators creates a degree of efficiency in experiments that cannot be matched by conducting observations in the real world. In tens of minutes on a simulator, it is possible to accomplish a study that might take months of real-world driving [62]. On the other hand, experiments are conducted in artificial study settings and generalisation of the results is questioned. Results from driving simulator studies cannot always be easily transferred to real traffic situations, since both the traffic environment and the vehicle characteristics are only approximations of reality. This is especially true in the simpler and static-based simulators. Simulators may not be total replicates of the real world, and indeed they cannot be. But they offer the researcher of driver behaviour an advantage that real-world studies cannot match: the ability to control experimental conditions and create prescripted scenarios.

A *naturalistic driving study* (NDS) can be defined as a study undertaken to provide insight into driver behaviour during everyday trips by observing in detail the driver, the vehicle and the surroundings through unobtrusive data gathering equipment and without experimental control [63]. Typically, in an NDS vehicles are equipped with several small cameras and sensors. For several months to several years, these devices inconspicuously record vehicle manoeuvres (such as speed, acceleration/deceleration, direction), driver behaviour (such as eye, head and hand movements), and external conditions (such as road, traffic and weather characteristics). *Naturalistic driving studies* allows for observing behaviour directly in a realistic context as drivers are observed during their everyday driving. Thus, the problem of the artificial study setting associated with experiments is alleviated. Also, observation of behaviours and factors leading to an incident or crash is observed, allowing for some interpretation of causality. The NDS method overcomes a range of problems associated with traditional approaches to data collection [64]: it yields information about normal behaviour and about all types of crashes, including property damage crashes, which may go unreported, and near-crashes, which are never reported; and it allows for direct observation of driver behaviours, without the previously noted biases and errors of traditional methods [65]. There are, however, some potential methodological and other limitations associated with the NDS method: they are very resource demanding in terms of sample recruitment, data gathering, data storage and data analysis [64]; driver behaviour may be influenced by knowledge of the presence of cameras and other sensors; crashes are rare events and thus very large sample sizes are needed to yield sufficient crash events; one does not have control over confounding variables as in experiments, so conclusions about causality are limited at best.

1.5 Structure of manuscript

Road users try to drive or behave in a safe way but the task is complex and the environment is not designed to prevent errors occurring. This research starts from a different perspective, i.e. that in many cases the design of the road environment can be further adjusted to human capabilities. The main objective for this dissertation is therefore to investigate human-road interaction in urban areas for different road users and for different road elements.

Six case studies analysing the human-road interaction with different approaches for different types of road users and for different road elements are presented in Chapters 2-7. The road users considered are different both for socio-demographic characteristics (age, gender) and for means of transport (drivers, pedestrian, bicyclists). The road elements considered are intersections (roundabouts and T-junctions) and pedestrian paths. The road users and the road elements analysed for each study are summarized in Table 1.1.

The first case study (Chapter 2) seeks to identify the roundabout geometric characteristics affecting the drivers' safety perception and the behaviour while the typical manoeuvres (entry, circulation, exit) are being carried out. The tool used was an on-line questionnaire, filled out by about 1.650 respondents. Four different dimensionality reduction methods (Cluster Analysis, Correspondence Analysis, Exploratory Factor Analysis and Confirmatory Factor Analysis) were used to analyse the data collected from the survey, in order to examine the key factors affecting the safety perception during the typical manoeuvres of roundabouts.

The second case study (Chapter 3) investigated the risk perception of roundabouts for young people in order to identify the major factors which influence such perception. A road users survey was developed to obtain young people feedback on roundabouts. Multiple Correspondence Analysis (MCA) was used in order to understand how the young people features, the geometric characteristics and the traffic conditions of roundabouts affect the respondents' risk perception.

Table 1.1 – Manuscript outline.

Chapter	Road users' characteristics	Road element	Data collection	Data analysis
CHAPTER 2	*Aim*: Evaluation of the geometric characteristics affecting the safety perception during the typical manoeuvres of roundabouts (entry, circulation, exit)			
	- Age: 18-70 - Gender: male, female - Travel mode: car, public transport, bicycle, pedestrian, motorcycles	- Roundabouts	- Self-reports (web survey)	- Cluster analysis - Correspondence analysis - Exploratory Factor analysis - Confirmatory Factor analysis
CHAPTER 3	*Aim:* Evaluation of the influence of socio-demographic characteristics, geometric characteristics and traffic conditions on young users' risk perception of roundabouts			
	- Age: 18-35 - Gender: male, female - Travel mode: car, motorcycles, pedestrian	- Roundabouts	- Self-reports (survey)	- Multiple correspondence analysis
CHAPTER 4	*Aim:* Evaluation of children's safety perception of home-school paths based on their parents' opinion			
	- Age: 3-11 - Gender: male, female - Travel mode: car, pedestrian	- Home-school paths	- Self-reports (survey)	- Path analysis
CHAPTER 5	*Aim:* Evaluation of drivers' physiological and behavioural responses when approaching T-junctions and roundabouts			
	- Age: 28-50 - Gender: male, female - Travel mode: drivers	- Roundabouts and T-junctions	- Driving study (speed, electrodermal activity)	- Continuous decomposition analysis - Association Rule
CHAPTER 6	*Aim:* Evaluation of the influence of the diameter of roundabouts on bicyclists' behaviour			
	- Age: Adults - Gender: male, female - Travel mode: bicyclists	- Roundabouts	- Naturalistic observations (speed, trajectories, surrogate safety indicators, helmet and reflective devices use)	- Univariate analysis of variance (ANOVA)
CHAPTER 7	*Aim:* Evaluation of the old pedestrians' safety perception of pedestrian paths			
	- Age: >70 - Gender: male, female - Travel mode: pedestrian	- Pedestrian paths	- Self-reports (survey)	- Cluster analysis

Chapter 4 reports a study regarding the safety of a particular category of road users, i.e. the children. Children can be part of the road environment as pedestrians or as bicyclists. The approach used for this study is the evaluation of children's safety perception of home-school paths based on their parents' opinions. In order to develop this analysis, the data collected from a survey conducted in front of 9 schools (kindergartens and primary schools) in Catania were used. A path analysis was carried out to analyse these data. The methodology used allowed to understand which elements favour parents' willingness to "trust" safe home-school paths in order to let their children walk to school. At the same time the data of the survey were used to evaluate parents' safety perception of the existing home-school paths and understand a correlation between the choice of walking or of driving to school.

The fourth case study (Chapter 5) intends to contribute for a better understanding of drivers' physiological and behavioural responses when approaching T-junctions and roundabouts. The ultimate aim is to understand how at grade intersections affect the driving behaviour by comparing speed and electrodermal activity variations induced by roundabouts with T-junctions. Speed and electrodermal activity were therefore collected continuously during a driving study which took place on a test environment based at Cranfield University and surrounding roads. The association Rule with the Apriori algorithm was used in order to evaluate associations between the variables related to electrodermal activity, i.e. the number and amplitude of the SCR peaks, and the variables related to speed, i.e. the speed variation and its sign (positive or negative), for each type of intersection.

Chapter 6 presents a study which makes use of semi-automated video observation software with the aim of analysing bicyclist behaviour and bicyclist safety on roundabouts with different diameters. The motivation for this research is to understand better bicyclist behaviour and how different geometric characteristics of roundabouts affect bicyclist safety. The video footages were processed using T-Analyst, a semi-automated video analysis tool, which allowed the accurate determination of the position of an object in the image and the calculation of its trajectory. This allowed the calculation of road users' speeds and positions in an accurate and objective way.

The sixth case study (Chapter 7) seeks to identify and characterize how old pedestrians perceive pedestrian paths with respect to their age related declines in perceptual and physical abilities and with respect to their experiences as road users. The final aim of this study was first of all to understand which critical issues old pedestrians found in the pedestrian paths they usually walk. Moreover, this study sought to analyze how old pedestrians' age related declines in perceptual and physical abilities (sight, hearing and mobility problems) and experiences as road user (no driving license, no still driving, accidents driving, accident pedestrian) can affect their opinion on the critical issues of pedestrian paths. In order to develop this analysis, the data collected from a survey conducted in Catania were used. A path analysis was carried out to analyse these data.

The final chapter (Chapter 8) presents the general discussion and conclusions of this dissertation.

The content of the five studies in chapters 2-7 were published or submitted for publication in scientific journal articles and conference proceedings:

- Chapter 2:
  Distefano, N., Leonardi, S., Pulvirenti, G., 2018. Factors with the greatest influence on drivers' judgment of roundabouts safety. An analysis based on web survey in Italy. IATSS Research, Vol. 42, Issue 4. DOI: 10.1016/j.iatssr.2018.04.002

- Chapter 3:
  Leonardi, S., Distefano, N., Pulvirenti, G., 2019. Multiple Correspondence Analysis (MCA) for the evaluation of risk perception of roundabouts for young people. European Transport, Issue 72, Paper n° 4, ISSN 1825-3997.

- Chapter 4:
  Distefano, N., Leonardi, S., Pulvirenti, G., 2019. Home-school travel: analysis of factors affecting italian parents' mode choice. Civil Engineering and Architecture, Vol 7 N. 3, Pages 75-87. DOI: 10.13189/cea.2019.070302

- Chapter 5:
  Distefano, N., Leonardi, S., Pulvirenti, G., Romano, R., Merat, N., Boer, E., Woolridge, E., 2019. Physiological and driving behaviour changes associated to different road intersections. Transportation Research Procedia. AIIT 2nd International Congress on Transport Infrastructure and Systems in a changing world. (TIS ROMA 2019), 23rd-24th September 2019, Rome, Italy

Distefano, N., Leonardi, S., Pulvirenti, G., Romano, R., Boer, E., Woolridge, E. Mining of the association rules between driver electrodermal activity and speed variation in different road intersections. Submitted for publication to Accident Analysis and Prevention.

- Chapter 6:
  Pulvirenti, G., De Ceunynck, T., Daniels, S., Distefano, N., Leonardi, S. Safety of roundabouts with mixed traffic: a video analysis of bicyclist behaviour. Submission in progress to Accident Analysis and Prevention.

- Chapter 7:
  Pulvirenti, G., Distefano, N., Leonardi, S. Elderly perception of critical issues of pedestrian paths. Submitted for publication to Civil Engineering and Architecture.

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2. FACTORS WITH THE GREATEST INFLUENCE ON DRIVERS' JUDGMENT OF ROUNDABOUTS SAFETY. AN ANALYSIS BASED ON A WEB SURVEY IN ITALY

This chapter assesses the safety perception of drivers on roundabouts during the execution of the different manoeuvres (entry, circulation, exit). The final aim is to understand how different geometric characteristics (single or double lane on the entry leg, on the exit leg and on the circulatory roadway) affect drivers' perception. The tool used was an on-line questionnaire, filled out by about 1.650 respondents. Four different dimensionality reduction methods (Cluster Analysis, Correspondence Analysis, Exploratory Factor Analysis and Confirmatory Factor Analysis) were used to analyse the data collected from the survey, in order to examine the key factors affecting the safety perception during the typical manoeuvres of roundabouts.

The study reported in this chapter was published in: *Distefano, N., Leonardi, S., Pulvirenti, G., 2018. Factors with the greatest influence on drivers' judgment of roundabouts safety. An analysis based on web survey in Italy. IATSS Research, DOI: 10.1016/j.iatssr.2018.04.002*

2.1 Introduction

In order to design well-functioning urban and rural road environments we need to have a good understanding of how we operate as road users. Consequently, there is a strong need to develop a good explanatory model for road behaviour. Such model should provide instructions to design the road, the traffic systems and their composing elements (nodes and arcs of road network) and, moreover, it should be easy to use. A model like this has to include a description of fundamental human behaviour with respect to moving around in the environment. Based on this description, it should be possible to establish the general principles upon which hypotheses should be formulated about how different parts of the road system should be designed. This explanatory model has to include realistic descriptions of various road user behaviours in order to accommodate the direct experiences we have as road users. Amongst others, the model should provide a good understanding of complex geometric and traffic conditions, and make up a good tool of analysis in order to understand the causes of various problems.

It is well known that intersections are among the most complex road environments: their geometric configuration, the signs and markings, the road furniture, the qualitative and quantitative characteristics of traffic, the vehicular conflicts are all elements which weigh the driver workload, conditioning the driving behaviour and, consequently, affecting the risk of accident. Several studies have related the geometric elements of intersections and users' safety perception. Alhajyaseen et al. [1] developed a technique to reproduce the variations in the paths of turning vehicles, considering the geometry of intersections, the vehicle type and the speed. The analysis revealed that the paths of right-turning vehicles are more sensitive to the vehicle speed and turning angle whereas those of left-turning vehicles are more sensitive to the intersection corner radius, turning angle, and vehicle speed. Anjana and Anjaneyulu [2] examined the crash causative factors of signalized intersections under mixed traffic using advanced statistical models. The prediction models helped to develop general safety countermeasures for signalized intersections and showed that exclusive left turn lanes and countdown timers are beneficial for improving the safety. Safety was also influenced by the presence of a surveillance camera, green time, median width, traffic volume, and proportion of two wheelers in the traffic stream.

Among intersections, roundabouts are, probably the most popular nowadays. The safety benefit of roundabout conversions has been recognized world-wide. A lot of researchers examined specifically the relationship between geometric elements and safety benefits in roundabouts. For example, Anjana and Anjaneyulu [3] identified the crash causes and devised safety performance measures for urban roundabouts located in the state of Kerala, India. Crash prediction models and crash modification factors were developed in this study for the safety assessment of geometric design features of roundabouts. The results of the analysis indicated that increasing the circulatory roadway width, exit angle, angle to the next leg, and splitter island width is associated with reduced crash rates at roundabout approaches. Elvik [4] proposed a meta-analysis of the road safety effects of converting junctions to roundabouts. Based on a meta-regression analysis, converting junctions to roundabouts was associated with a reduction of fatal accidents of about 65% and a reduction of injury accidents of about 40%. The mean effect on property-damage-only accidents was ambiguous. The severity of the crashes on large sample roundabouts in Flanders-Belgium was examined by Daniels et al. [5] in order to investigate which factors might explain the severity of crashes or injuries and to relate these factors to the existing knowledge about contributing factors for injury severity in traffic. Logistic regression and hierarchical binomial logistic regression techniques were used. A clear externality of risk appeared to be present in the sense that vulnerable road user groups (pedestrians, bicyclists, moped riders and motorcyclists) were more severely affected than others. Fatalities or serious injuries in multiple-vehicle crashes for drivers of four-wheel vehicles were much rarer. Injury severity increased with higher age. Crashes at night and crashes outside built-up areas were more severe. Single-vehicle crashes seemed to have more severe outcomes than multiple-vehicle crashes.

Sadeq and Sayed [6] used automated video-based traffic conflicts analysis to diagnose safety issues at a roundabout in Vancouver, British Columbia, Canada. Traffic conflicts were automatically identified and analysed to develop an in-depth understanding of the behaviour of road users and the causes of traffic conflicts. Conflicts contributing factors were identified and safety countermeasures were presented. Kim and Choi [7] investigated data concerning crashes at roundabouts in order to identify the major factors influencing such events in South Korea. Field surveys were conducted in order to investigate how vehicle speeds influenced the occurrence of accidents and a statistical analysis was performed in order to investigate the correlation between roundabout geometry and crash occurrences and to reveal major geometric elements of roundabout safety. The study provided a model apt to capture the relationship between geometric design elements and the occurrence of crashes at roundabouts. Wang et al. [8] investigated a sample of driver evaluations of the perception of safety associated with a set of typical road environments. A roundabout was selected as the context for the empirical study. Data were obtained by a computerized survey using the video-captured road and traffic situations. An indicator of perceived safety was developed for a number of typical road and traffic situations and for different driver segments.

Montella [9] identified the crash contributory factors at urban roundabouts. Numerous contributory factors related to deficiencies of the roundabouts but not related to the road user or to the vehicle were identified. The most important factors related to geometric design were the radius of deflection and the deviation angle. Furthermore, because of the association between the markings, signs, and geometric design contributory factors, the study results suggested that the improvement in markings and signs might also have a significant effect in the sites where geometric design deficiencies were identified as contributory factors.

Gross et al. [10] estimated the safety effectiveness of converting signalized intersections to roundabouts. The empirical Bayes (EB) method was employed in an observational before-after study to estimate the safety effects. Data from select states were also used in a cross-sectional analysis to investigate the compatibility of results from cross-sectional and before-after studies. The EB results indicated a safety benefit for converting signalized intersections to roundabouts. Based on the cross-sectional analysis, it appeared that roundabouts have the potential to significantly reduce crashes and severity at signalized intersections.

Therefore, the different studies on roundabouts show that, despite the high level of safety recognized for this type of intersection, there are several factors influencing the driver behaviour. These factors occasionally cause incorrect behaviours which can degenerate into accidents. Such factors are predominantly geometric (entry and exit width, circulatory roadway width, entry radius, deflection angle, etc.) and may affect the perception of one or more of the three typical roundabout manoeuvres: entry manoeuvre, exit manoeuvre and manoeuvre on the circulatory roadway. However, the judgment on how dangerous these manoeuvres are, is not always unequivocal: the driver's perception of danger may vary significantly in relation to the geometric characteristics of the roundabouts elements. The driving experience, deriving from road characteristics to which the driver is used to, plays a key role in the formulation of such judgment. In Italy roundabouts are now very common in both urban and rural areas. However, roundabouts are very different in shape, size and traffic conditions throughout the country. Moreover, the driver behaviour is not uniform among drivers in Italy. Because of this, a deep understanding of the driver safety perception in roundabouts requires a large sample of users coming from different regions, who are therefore used to different road infrastructures characteristics.

The aim of this paper is to identify the roundabout geometric characteristics affecting safety perception during the typical manoeuvres (entry, circulation, exit). The tool used was an on-line questionnaire, filled out by about 1.650 respondents. In order to analyse the data four different kinds of statistical analyses (Cluster Analysis, Correspondence Analysis, Exploratory Factor Analysis and Confirmatory Factor Analysis) were chosen, with the aim of summarizing the vast amount of data that typically originate from a survey conducted on a large number of users. While there is a substantial body of literature on the application of traditional statistical methods (Univariate Analysis, Bivariate Analysis, Multivariate Analysis, Logistic Regression, and Loglinear Modeling) in transportation research, there are few studies in transportation research focused on application of the dimensionality reduction methods, such as Correspondence Analysis, Cluster Analysis and Factorial Analysis.

Correspondence analysis is usually employed to identify patterns in large and complex datasets. Jalayer and Zhou [11] used Multiple Correspondence Analysis to evaluate the roadway/environmental, motorcycle, and motorcyclist-related variables that affect the severity and frequency of at-fault motorcycle-involved crashes. Factor et al. [12] examined the link between social characteristics and road-accident involvement. Using a large database that merged official Israeli road-accident records with socioeconomic data from two censuses, this research mapped the social order of road accidents through Multiple Correspondence Analysis.

Cluster analysis has previously been used to examine transportation issues related to the level of engagement with an in-vehicle secondary task [13], transport risk perception [14] and the risk for cyclists to be injured in a road accident [15].

Factorial analysis is probably the most popular method to analyse interrelationships among a large number of variables, expressed by continuous data, grouping them in few factors or components explaining the original variables. Monterde i Bort [16] tested whether the original factorial structure of a recklessness questionnaire can be maintained for the current Spanish population of older drivers. Sraji and Tjahjono [17] used Factorial Analysis to study motorcycle aspect on accident risks including tires, brakes, lamps, engines, chassis, mirrors, conspicuity, and equipment for riding. A lot of transportation researchers used Factorial Analysis to analyse the driver behaviour [18, 19, 20].

Some researchers applied more than one of these analyses to examine the data thoroughly. For example, Usami et al. [21] studied behavioural tendencies of drivers to distraction, aggressiveness, indiscipline and insecurity through Multiple Correspondence Analysis. Then, through Cluster Analysis, they identified seven groups of drivers with similar behaviours. Arnau-Sabates et al. [22] used factorial and Cluster Analysis to explore the association between awareness of road safety measure and accident involvement in young pre-drivers. The Exploratory Factorial Analysis was used in order to group the questionnaire variables together, then the Cluster Analysis was performed to identify different risky pre-driver groups.

In this study the four above mentioned dimensionality reduction methods were used to analyse the data collected from an on-line questionnaire, in order to examine the key factors affecting the safety perception during the typical roundabout manoeuvres. The final aim was the evaluation of the influence of roundabout design options on the perceived safety during the different manoeuvres.

2.2 Methodology

2.2.1 Survey

A 30 items questionnaire was used to collect the participants' opinions. The questionnaire was divided into the following 5 sections:

- Section 1: participants reported their age, gender and other basic demographic information in this section.
- Section 2: in the second section questions were asked about the means of transport mainly used, the overall opinion on roundabouts, the frequency of roundabouts use and the knowledge of how a roundabout works.
- Section 3: the third section included questions about the safety perception in roundabouts from the point of view of different categories of users (drivers, pedestrians, cyclists, motorcyclists).
- Section 4: in the fourth section participants were asked questions about the safety perception in roundabouts as for the different manoeuvres (entry, circulation, exit) and in relation to the geometry (single lane, double lane). The fourth section questions have been formulated in such a way as to solicit spontaneous opinions on safety, based on the respondents' driving experiences on roundabouts without reference to roundabouts actually existing. This was done in order to obtain general opinions on the safety perception in relation to the various roundabout design options.
- Section 5: the fifth section concerned 4 pairwise comparisons related to 8 existing roundabouts located in different urban Italian context. These roundabouts were chosen as representative examples of different geometric design options. The roundabouts have been proposed to the respondents through Google images. For each couple of roundabouts, respondents were only asked to choose the roundabout they perceived as safer.

Figure 2.1 schematically shows the questionnaire structure.

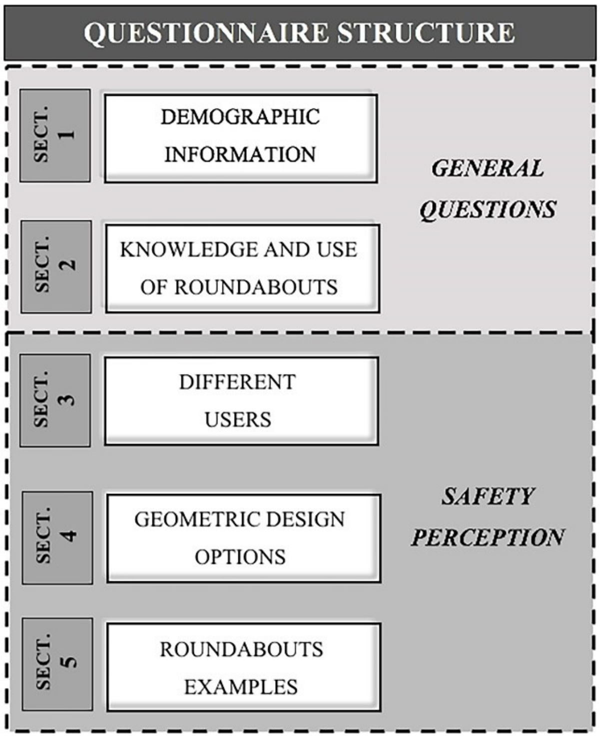

Figure 2.1 - Questionnaire structure.

The questionnaire underwent thorough piloting and revision, through 20 interviews face to face with professors and researchers of the University of Catania. This was done to ensure the suitability of the questions for the target people and to assess the acceptability of the wording, as well as the understanding of the questions.

The online survey was created with Google Forms Software. Then it was made available online on the DISS (Italian Centre of Road Safety) web-site. DISS is an Applied Research Centre actively involved in all sectors of road safety. DISS members are university professors and researchers engaged in road safety issues (infrastructures, vehicles, human factor). The survey data were collected over a 9-month period in 2016/2017.

As the respondents' sample was composed by Italian people, all questions were referred to right-hand drive. Therefore, in the countries in which motorists drive on the opposite side of the road, all conventions referred to would need to be adjusted accordingly. Nevertheless, the authors do not believe that this is a limit for this study, as all the questions considered for the following analysis are not directly affected by the right/left-hand drive.

Since the goal of this study was to deduce how roundabout geometric factors affect the users' safety perception during the typical roundabout manoeuvres, the results of the fourth section of the questionnaire were analysed. Table 2.1 shows the section 4 questions. The respondents' answers to these questions do not refer (are not referred) to specific roundabouts, but they are based on the respondents' driving experience on roundabouts due to the presence of several roundabouts in Italy, both in urban and rural areas.

The respondents' answers to these questions do not refer to specific roundabouts, but they reflect the respondents' safety perception arising from their driving experience on roundabouts due to the presence of several roundabouts in Italy, both in urban and rural areas.

Table 2.1 - Section 4 questions.

QUESTIONNAIRE – SECTION 4	
Which do you think is the most dangerous manoeuvre on a roundabout?	Entry manoeuvre Manoeuvre on the circulatory roadway Exit manoeuvre
Do you feel safer entering a roundabout if:	The roundabout has one entry lane The roundabout has one circulating lane Both the previous situations None of the previous situations I don't know
Do you feel safer exiting a roundabout if:	The roundabout has one exit lane The roundabout has one circulating lane Both the previous situations None of the previous situations I don't know
Do you feel safer circulating a roundabout if:	The roundabout has one circulating lane The roundabout has two circulating lanes I don't know

2.2.2 Participants

Participants for this study were recruited through an online survey. The total sample comprised 1.716 participants. The participants who didn't complete the questionnaire or who gave uncertain answers (e.g. "I don't know") were excluded. The respondents excluded were only 4% of the sample. This low percentage was probably due to the fact that the interviewees' sample was mainly composed by people engaged in the field of road safety, who were acquainted with the topics covered in the questionnaire. The final sample was 1.649 participants.

All participants included in the study had a driver's license. The majority of respondents (around 36%) were below the age of 25; however, significant percentage of the participants were aged between 26 and 35 years (around 24%) and between 36 and 50 (around 24%). Above 50 year-olds were less important percentage of respondents (16,01%). As for sex, the males were slightly more numerous than females (about 56% of the sample was made up of men and about 44% were women). The travel mode most frequently used was definitely the car (71,68%); there were still significant percentage of bicyclists (10,19%) and public transport users (8,67%), while only 5,52% of respondents were more likely to move on foot and only 3,94% of respondents mainly used motorcycle. Almost all participants (95,57%) used to travel through a roundabout at least once a day. Participants' characteristics are presented in Table 2.2.

Table 2.2 - Features of survey respondents.

Category	*Number*	*Percent*
Age		
18-25	594	36,02
26-35	401	24,32
36-50	390	23,65
51-70	264	16,01
Total	1.649	100,00
Gender		
Male	926	56,16
Female	723	43,84
Total	1.649	100,00
Travel mode		
Car	1.182	71,68
Public Transport (bus, metro, train)	143	8,67
Bicycle	168	10,19
On foot	91	5,52
Motorcycle	65	3,94
Total	1.649	100,00
Frequency of roundabout use		
At least once a day	1.576	95,57
Less than once a day	73	4,43
Total	1.649	100,00

2.2.3 Methods for analysis and model development

Carrying out a thorough analysis of the key factors affecting the safety perception during the typical roundabout manoeuvres was the final aim of this study. The method selected to conduct this analysis was the Structural Equation Modelling. Structural Equation Modelling (SEM) is notoriously a very general statistical modelling technique widely used in the field of behavioural sciences. It can be viewed as a combination of Factor Analysis and Regression or Path Analysis. The interest in SEM is often on theoretical constructs, which are represented by the latent factors. The relationships between the theoretical constructs are represented by regression or path coefficients between the factors. Confirmatory Factor Analysis (CFA) is a special case of Structural Equation, in which relationships among latent variables are modelled as covariance/correlations rather than as structural relationships (i.e., regressions). CFA can also be distinguished from Exploratory Factor Analysis (EFA) in that CFA requires researchers to specify explicitly all characteristics of the hypothesized measurement model (e.g., the number of factors, pattern of indicator-factor relationships) to be examined whereas EFA is more data-driven.

An operational procedure starting from preliminary statistical analysis, aimed at finding the most appropriate way to develop the CFA, was adopted. For this reason, the main factors affecting the drivers' safety perception while performing the various roundabout manoeuvres were discovered using Correspondence Analysis (CA) and Cluster Analysis. The Correspondence Analysis (CA) is a descriptive method for analysing categorical multivariate data. The method converts the data matrix into a diagram, generally two-dimensional (biplot), wherein rows and columns are presented as points in space. The biplots are interpreted by looking at groupings of variables in space. Points (items) that are close to the mean are plotted near the diagram origin, and those that are more distant are plotted farther away. Items with a similar distribution are presented near one another, while those with different distributions are farther apart.

The variables used for Correspondence Analysis were two: variable 1 describes users' safety perception by means of 13 items listed in Table 2.3 (S1, S2, ..., S13); variable 2 describes the types of users according to their safety perception about the three possible roundabout manoeuvres by means of 3 items (U1, U2 and U3) listed in Table 2.3.

Table 2.3 - Variables and related items for Correspondence Analysis

	Variable 1 – Safety perception
S1	I feel safer entering a roundabout if the roundabout has one entry lane
S2	I feel safer entering a roundabout if the roundabout has one circulating lane
S3	I feel safer entering a roundabout if the roundabout has one entry lane and one circulating lane
S4	I don't feel safer entering a roundabout if the roundabout has one entry lane and one circulating lane
S5	I don't know when I feel safer entering a roundabout
S6	I feel safer exiting a roundabout if the roundabout has one exit lane
S7	I feel safer exiting a roundabout if the roundabout has one circulating lane
S8	I feel safer exiting a roundabout if the roundabout has one exit lane and one circulating lane
S9	I don't feel safer exiting a roundabout if the roundabout has one exit lane and one circulating lane
S10	I don't know when I feel safer exiting a roundabout
S11	I feel safer circulating a roundabout if the roundabout has one circulating lane
S12	I feel safer circulating a roundabout if the roundabout has two circulating lanes
S13	I don't know when I feel safer circulating a roundabout
	Variable 2 – Types of users
U1	Users who consider the entry manoeuvre the most dangerous
U2	Users who consider the exit manoeuvre the most dangerous
U3	Users who consider the manoeuvre on the circulatory roadway the most dangerous

The data used for the Correspondence Analysis were also analysed by using agglomerative hierarchical Cluster Analysis. The goal of Cluster Analysis was to classify cases into homogeneous groups or clusters. Between-groups linkage was used as the method for combining clusters. This method combines clusters to minimize the average distance between all pairs of items in which one member of the pair is from each of the clusters. Distance is a measure of how far apart two objects are, and similarity measures closeness. Distance measures are small and similarity measures are large for cases that are similar. The cosine distance using standardized data was chosen as the measure of similarity. To visualize the results of the hierarchical clustering calculation, a tree-structured graph (dendrogram) was used.

After having conducted Correspondence and Cluster Analysis, the items significantly affecting the safety perception of each of the three categories of users examined (U1, U2 e U3) were selected. An Exploratory Factor Analysis (EFA) was carried out on these items. Such EFA analysis was essential to name the latent factors extracted from the vast amount of starting data. The Exploratory Factor Analysis is a statistical technique used for reducing data to a smaller set of summary variables and to explore the underlining theoretical structure of the phenomena. It is used to identify the structure of the relationship between the variable and the respondent. In this research, the Exploratory Factor Analysis was performed using the principal components method, with Varimax rotation. The suitability of data for

Factor Analysis was assessed with the Kaiser-Meyer-Oklin (KMO) and the Barlett's Tests of Sphericity. The data were considered suitable for factorial analysis when KMO > 0,50 and the null hypothesis (H0) was rejected (p-value ≤ 0,05). To help establishing the correct number of factors to be extracted from the Factorial Analysis, the criteria used were: i) the Kaiser criteria, to retain factors with eigenvalue >1; ii) Cattel Scree Plot criteria, which implies the retention of all components in the sharp descent part of the plot before the eigenvalues start to level off, where line changes slope. The selection of the items for each factor consisted in retaining items that showed strong factor loadings. As it is the practice, items with factor loadings >0,3 were chosen. The results of the EFA will be illustrated in the following paragraph 3.2 through the pyramid diagrams, explicitly introduced in this study. The pyramid diagram has a hierarchical structure and is subdivided into a number of sections equal to the items with significant saturation for each of the extracted factors. The items related to the factors explaining the greater variance are at the top of the pyramid. Each section is identified by the "+" or the "-" sign and is associated with the specific item that saturates the corresponding factor, positively or negatively. The items related to each factor are sorted in descending order on the basis of the absolute value of saturation; such sorting gives rise to the ordered sequence of the signs attributed to the single sections constituting the pyramid structure. Lastly, using the pyramid diagram, the names to be attributed to the latent factors extracted by Explorative Factor Analysis can be defined.

After having carried out the Exploratory Factor Analysis, the Confirmatory Factor Analysis (CFA) was applied. Such analysis gave us the final factorial structure represented by the path diagrams. The Confirmatory Factor Analysis examines how well the presumed theoretical structure of the factor model fits the real data. From the analysis and comparison of the results of the CFA, the most fitted models were chosen and their internal consistency was assessed using the data number subdivided for each of the three categories of users considered (n = 872, for users considering the entry manoeuvre the most dangerous; n = 195, for users considering the manoeuvre on the circulatory roadway the most dangerous; n = 582, for users considering the exit manoeuvre the most dangerous). The final SEM model confirmed our theory concerning the influence of roundabout design options on the safety perception.

SPSS version 24.0 was used for Correspondence Analysis, Cluster Analysis and Exploratory Factor Analysis. AMOS software version 24.0 was used for Confirmatory Factor Analysis.

2.3 Results and discussion

2.3.1 Correspondence Analysis and Cluster Analysis

A two-dimensional representation has proved to be sufficient to explain the majority of inertia (98%) with reference to the data processed in this study. The output of the Correspondence Analysis obtained through the SPSS software is the biplot shown in Figure 2.2.

As it can be seen from Figure 2.2, the first factor (dimension 1) represents the safety perception scale associated with different geometric elements of roundabouts: on the left, there are the items corresponding to the geometric configurations considered the safest when carrying out entry and exit manoeuvres (configurations with one circulating lane); in the middle are grouped the items related to the geometric configurations perceived as of average safety when carrying out the three possible manoeuvres (single-lane configurations with special regard to consecutive single-lane elements); on the right, there are the items corresponding to the geometric configurations considered less safe (configurations with two circulating lanes).

The second factor (dimension 2) is more difficult to interpret: at the top there are the items referred to specific geometric configurations, while at the bottom the items expressing uncertainty in the safety perception prevail (S4, S5, S9, S10, S13).

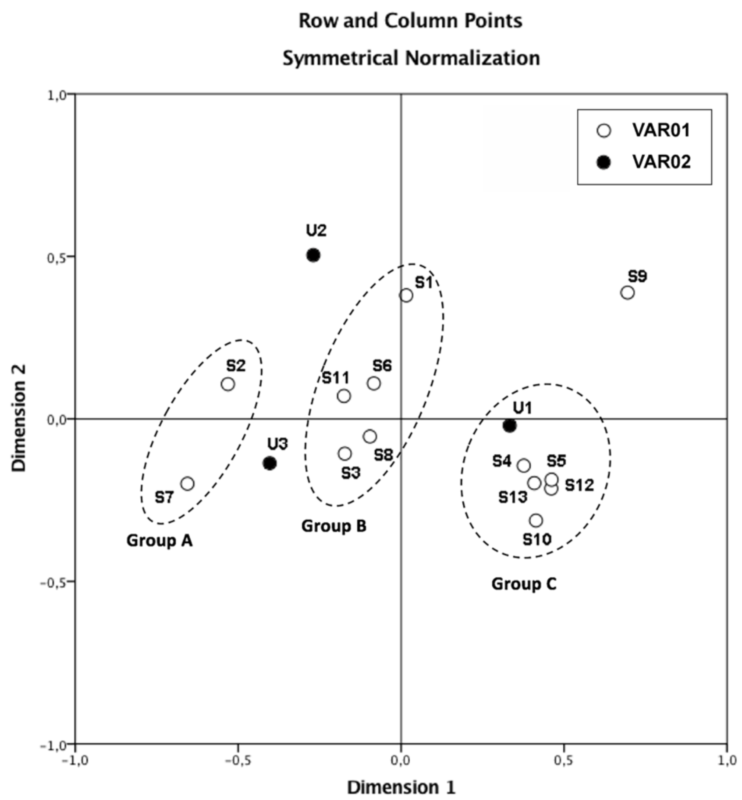

Figure 2.2 - CA Biplot of all variables studied.

The graph also shows three groups of items: a) the left one, grouping the situations considered to be determinant to ensure an adequate level of safety in roundabout (namely one circulating lane, which is highly appreciated by users when present and causes discomfort and unsafety when absent), b) the middle one, including the configurations considered safe but expected (their absence is unthinkable), c) the right one, representative of all situations of unsafety and of uncertainty (two circulating lanes) which result in a total perception of unsafety.

In support of the Correspondence Analysis, as stated in paragraph 2.4, a Cluster Analysis was conducted. The results obtained by applying Cluster Analysis to the factorial scores obtained from Correspondence Analysis are represented in the dendrogram in Figure 2.3. By cutting the dendrogram at height 6, corresponding to the highest jump between levels of similarity, three clusters homogeneous as for their level of perceived safety are obtained. These clusters correspond to the three groups (A, B and C) resulting from the Correspondence Analysis.

Figure 2.2 also shows the items related to the variable named "types of users". All the three items are in a position almost equidistant from the origin and, therefore, there does not seem to be a category of users prevailing among the others regarding the safety perception during the three possible manoeuvres. Nevertheless, the first item (users considering the entry manoeuvre the most dangerous) being located on the right of the abscissa axis and within the group representative of the unsafety perception, is perhaps the one representative of the users more sensitive to unsafety issues in roundabouts.

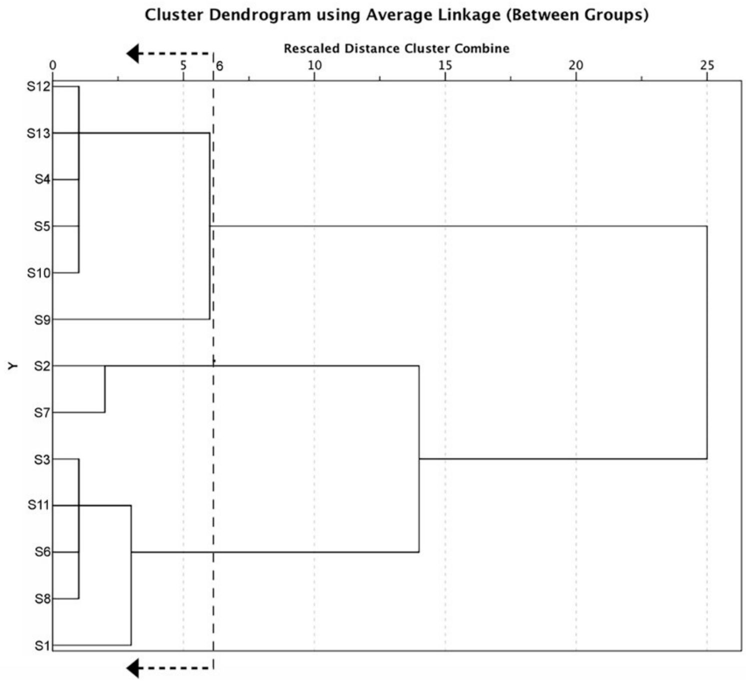

Figure 2.3 - Cluster Analysis Dendrogram of safety perception variable.

Ultimately, Correspondence and Cluster Analysis confirmed that safety perception is strongly correlated to roundabouts design elements. All judgements related to situations of unsafety and uncertainty have been considered of little interest in the characterization of the users’ safety perception. Therefore, the subsequent Factorial Analysis will be carried out by purifying the database from all these answers (S4, S5, S9, S10, S13).

2.3.2 Factorial Analysis

The outcomes of the analysis carried out in the previous paragraph suggested the reduction in the number of variables from 13 to 8. Therefore, the surviving variables are the following:

- item 1: one entry lane;
- item 2: one circulating lane;
- item 3: one entry lane and one circulating lane;
- item 4: one exit lane;
- item 5: one circulating lane;
- item 6: one circulating lane and one exit lane;
- item 7: one circulating lane;
- item 8: two circulating lanes.

In order to conduct the Exploratory Factor Analysis and the Confirmatory Factor Analysis, the original database was divided into three parts: 1) portion of the answers database (N = 872) given by users who considered the entry manoeuvre the most dangerous in roundabout; 2) portion of the answers database (N = 195) given by users who considered the manoeuvre on the circulatory roadway the most dangerous in roundabout; 3) portion of the answers database (N = 582) given by users who considered the exit manoeuvre the most dangerous in roundabout.

The Factorial Analysis was conducted separately for each of the three portions of the database.

2.3.2.1 Results related to users who consider the entry manoeuvre the most dangerous

The output of the Exploratory Factor Analysis for users who consider the entry manoeuvre the most dangerous is the pyramid diagram of the safety perception shown in Figure 2.4.

The first factor, with the greatest explained variance (27,03%), includes four items with significant saturations. Two items, with positive sign, indicate one entry lane and one circulating lane (item 3) and one exit lane and one circulating lane (item 6). Two items, with negative sign, indicate one entry lane (item 1) and one exit lane (item 4). The negative sign of an item indicates that its saturation is negative, and, therefore, its contribution to the factor is inverse (this means that the geometric elements represented by the item affect negatively the safety perception).

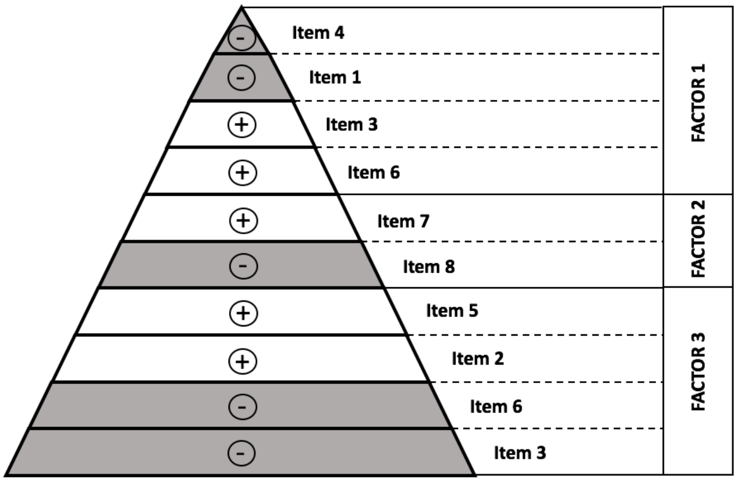

Figure 2.4 - EFA Pyramid diagram (users who consider the entry manoeuvre the most dangerous).

The second factor, next in importance (24,16% of explained variance), includes two items with significant saturations. One item, with positive sign, indicates one circulating lane (item 7) and one item, with negative sign, indicates two circulating lanes (item 8).

Lastly, the third factor (20,62% of explained variance) groups together two items, with positive sign, that indicate one circulating lane (item 2) and one circulating lane (item 5) and two items, with negative sign, that indicate one entry lane and one circulating lane (item 3) and one exit lane and one circulating lane (item 6).

From the analysis of the diagram of Figure 2.4, we can draw the following considerations:

- the items affecting positively the safety perception and saturating significantly the first factor indicate the importance that the consecutive geometric elements of a roundabout (entrance / circulatory roadway, circulatory roadway / exit) are organized with one lane. Therefore, the first factor assumes the following name: "Importance of the geometric coherence of two consecutive elements";
- the second factor items enable to identify the users' preference for the configurations with one circulating lane. Such configurations ensure the best safety perception for the manoeuvre on the circulatory roadway. Therefore, the second factor is named "Importance of one circulating lane for the safety of the manoeuvre on the circulatory roadway";

- the items saturating the third factor show that the safety perception for entry and exit manoeuvres is greater in the case of roundabout configurations with one circulating lane. Therefore, the third factor assumes the following denomination: "Importance of one circulating lane for the safety of exit and entry manoeuvres".

The Exploratory Factor Analysis, ultimately, shows that:

according to users who consider the entry manoeuvre the most dangerous, the factor called "Importance of the geometric coherence of two consecutive elements" is extremely significant;

the highest degree of perceived safety is always associated with geometric configurations with one lane. In particular, the users who perceive the entry manoeuvre the most dangerous focus on the importance of one circulating lane.

In light of the above considerations, the Confirmatory Factor Analysis (CFA) has been developed considering the two so-called factors "Perceived safety on individual geometric elements with one lane" and "Perceived safety on consecutive geometric elements with one lane".

The Confirmatory Analysis calculations were carried out with reference to the items identifying univocally different geometric conditions. These items are the following 6 (the first four are associated with the first factor and the last two are associated with the second factor):

- item 1: one entry lane;
- item 2: one circulating lane;
- item 3: one exit lane;
- item 4: two circulating lanes;
- item 5: one entry lane and one circulating lane;
- item 6: one circulating lane and one exit lane.

The results of the Confirmatory Factor Analysis are shown in the path diagram of Figure 2.5. These results can be summarized as follows:

- the slightly positive covariance of the two factors considered (0,12) shows that, from the point of view of safety, the users who consider the entry manoeuvre the most dangerous judge positively both the roundabouts characterized by geometric coherence of two consecutive elements and the individual geometric elements with a lane;
- the standardized regression coefficients show that the first factor is predominantly explained by the presence of one circulating lane in the

positive sense (+0,66) and by two circulating lanes in the negative sense (i.e. inverse);

- with regard to the second factor, the highest level of safety is explained by the geometric coherence of the succession represented by one entry lane and one circulating lane (+ 1,02).

Ultimately, users who consider the entry manoeuvre the most dangerous tend to consider safer one circulating lane configurations, even better if they are also characterized by one entry lane. This means that their foremost concern in entering a roundabout is the presence of two circulating lanes.

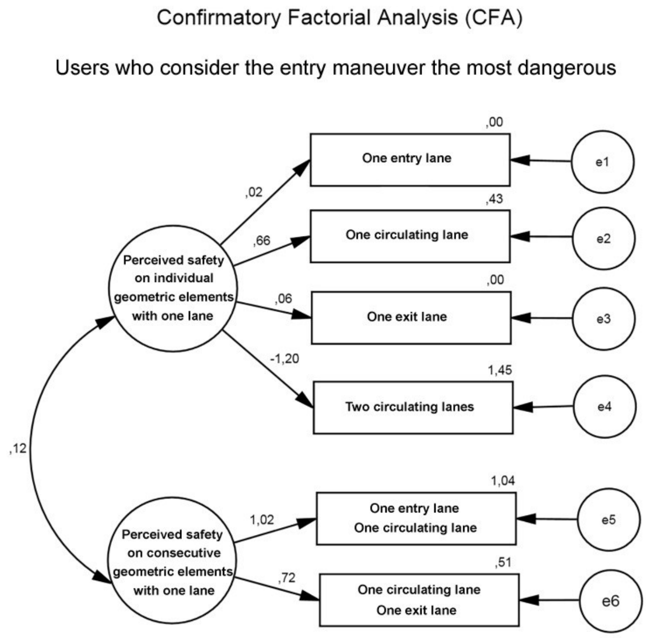

Figure 2.5 - CFA path diagram of the perceived safety by users who consider the entry manoeuvre the most dangerous.

2.3.2.2 Results related to users who consider the manoeuvre on the circulatory roadway the most dangerous

The output of the Exploratory Factor Analysis for users who consider the manoeuvre on the circulatory roadway the most dangerous is the pyramid diagram of the safety perception shown in Figure 2.6.

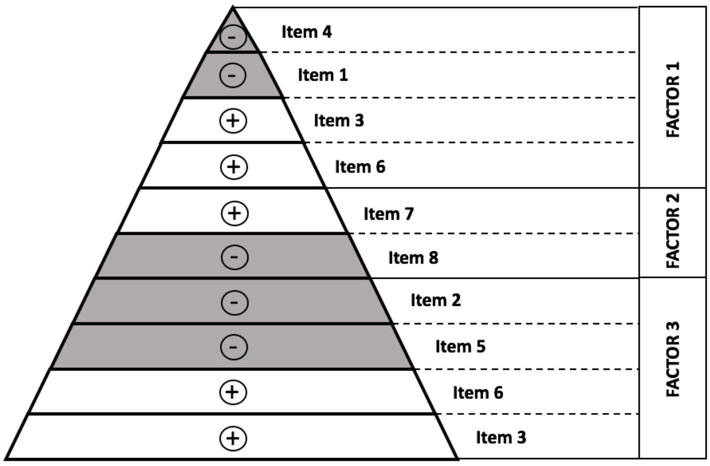

Figure 2.6 - EFA Pyramid diagram (users who consider the manoeuvre on the circulatory roadway the most dangerous).

The first factor, with the greatest explained variance (28,20%), includes four items with significant saturations. Two items, with positive sign, indicate *one entry lane and one circulating lane* (item 3) and *one exit lane and one circulating lane* (item 6). Two items, with negative sign, indicate *one entry lane* (item 1) and *one exit lane* (item 4).

The second factor (24,07% of explained variance), includes two items with significant saturations. One item, with positive sign, indicates the *one circulating lane* (item 7) and one item, with negative sign, indicates *two circulating lanes* (item 8).

The third factor with the smallest explained variance (21,44%), groups together four items with significant saturations. Two items, with positive sign, indicate *one entry lane and one circulating lane* (item 3) and *one exit lane and one circulating lane* (item 6). Two items, with negative sign, indicate *one circulating lane* (item 2) and *one circulating lane* (item 5).

From the analysis of the diagram of Figure 2.6, we can draw the following considerations:

- as it was the previous case, the items affecting positively the safety perception indicate the importance that the consecutive geometric elements of a roundabout (entrance / circulatory roadway, circulatory roadway / exit) are organized with one lane. Therefore, the first factor assumes the following name: "Importance of the geometric coherence of two consecutive elements";
- the second factor items enable to identify the users' preference for the configurations with one circulating lane. Such configurations ensure the best

safety perception for the manoeuvre on the circulatory roadway. Therefore, the second factor is named "Importance of one circulating lane for the safety of the manoeuvre on the circulatory roadway";

- the items saturating the third factor show that, from the point of view of safety, users prefer the geometric coherence of consecutive elements rather than one circulating lane. Therefore, the third factor can assume the same denomination of the first.

Just as in the previous case, the Exploratory Factor Analysis shows that:

- the factor called "Importance of the geometric coherence of two consecutive elements" is extremely significant;
- the highest degree of perceived safety is always associated with geometric configurations with one lane. In the specific case, the presence of one circulating lane is fundamental.

In light of the above considerations, here again, the Confirmatory Factor Analysis (CFA) has been developed considering the two so-called factors "Perceived safety on individual geometric elements with one lane" and "Perceived safety on consecutive geometric elements with one lane". Moreover, the CFA calculations were carried out with reference to the same 6 items of the previous case, which identify univocally the different geometric conditions.

The results of the Confirmatory Factor Analysis are shown in the path diagram of Figure 2.7. These results can be summarized as follows:

- also the users who consider the manoeuvre on the circulatory roadway the most dangerous, show a preference for single lane roundabouts;
- the high level of perceived safety on the configurations with one circulating lane is particularly noticeable. Indeed, the standardized regression coefficients show that the factor "Perceived safety on individual geometric elements with one lane" is strongly linked in a positive way (+ 0,95) to one circulating lane and in a negative way (-0,91) to two circulating lanes;
- with regard to the factor "Perceived safety on consecutive geometric elements with one lane", the highest standardized coefficient (+ 0,92) is the one related to one entry lane and one circulating lane.

Ultimately, also the users who consider the manoeuvre on the circulatory roadway the most dangerous perceive as safer the roundabouts with one circulating lane, similarly to users who consider the entry manoeuvre the most dangerous. Their foremost concern is therefore having to circulate on a two-lanes circulatory roadway.

Ultimately, also the users who consider the manoeuvre on the circulatory roadway the most dangerous perceive as safer the roundabouts with one circulating lane, similarly to users who consider the entry manoeuvre the most dangerous. Their foremost concern is therefore having to circulate on a two-lanes circulatory roadway.

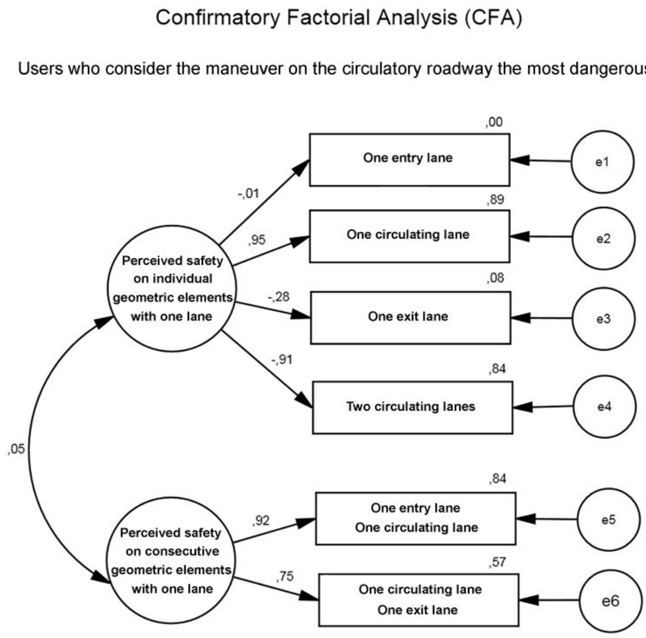

Figure 2.7 - CFA path diagram of the perceived safety by users who consider the manoeuvre on the circulatory roadway the most dangerous.

2.3.2.3 Results related to users who consider the exit manoeuvre the most dangerous

The output of the Exploratory Factor Analysis for users who consider the exit manoeuvre the most dangerous is the pyramid diagram of the safety perception shown in Figure 2.8.

The first factor, with the greatest explained variance (25,07%), includes four items with significant saturations. Two items, with positive sign, indicate one entry lane (item 1) and one exit lane (item 4). Two items, with negative sign, indicate one entry lane and one circulating lane (item 3) and one exit lane and one circulating lane (item 6).

The second factor, next in importance (24,23% of explained variance), groups together four items with significant saturations. Two items, with positive sign, indicate one entry lane and one circulating lane (item 3) and one exit lane and one circulating lane (item 6). Two items, with negative sign, indicate one circulating lane (item 2) and one circulating lane (item 5).

Lastly, the third factor (23,76% of explained variance) includes one item, with positive sign, that indicates one circulating lane (item 7) and one item, with negative sign, that indicates two circulating lanes (item 8).

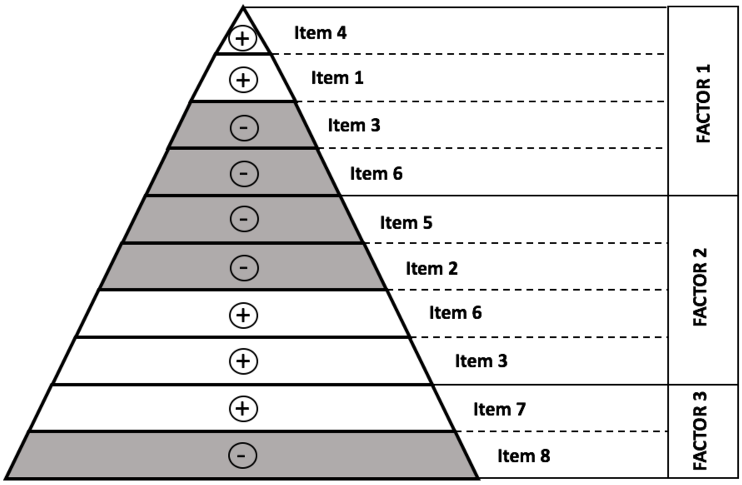

Figure 2.8 - EFA pyramid diagram (users who consider the exit manoeuvre the most dangerous).

From the analysis of the diagram of Figure 2.8, we can draw the following considerations:

- the items that define the first factor enable to identify the users' preference for configurations with one-lane legs (both entry leg and exit leg). Therefore, the second factor can be called: "Importance of one-lane legs";
- the items saturating the second factor show that users perceive a higher level of safety when the consecutive geometric elements of the roundabout (entrance / circulatory roadway, circulatory roadway / exit) have a single lane. Therefore, the second factor can assume the following name: " Importance of the geometric coherence of two consecutive elements";
- the third factor items demonstrate that, as for the manoeuvre on the circulatory roadway, users perceive the highest level of safety in the case of configurations with one circulating lane. Therefore, the third factor is named "Importance of one circulating lane for the safety of the manoeuvre on the circulatory roadway".

The Exploratory Factor Analysis, ultimately, shows that:

- just as in the previous two cases, the factor called "Importance of the geometric coherence of two consecutive elements" is extremely significant;
- just as in the previous two cases, the highest degree of perceived safety is always associated with geometric configurations with one lane. In particular, the users who consider the exit manoeuvre the most dangerous feel more the need of having one-lane legs (one entry lane and one exit lane).

In light of the above considerations, also in this case the Confirmatory Factor Analysis (CFA) has been developed considering the same two factors and the same 6 items taken into account in the previous cases.

The results of the Confirmatory Factor Analysis are shown in the path diagram of Figure 2.9. These results can be summarized as follows:

- the users prefer the exit with one lane. Indeed, observing the standardized regression coefficients, we can see that the factor "Perceived safety on individual geometric elements with one lane" is mainly linked in a positive way (+ 0,66) to the presence of one exit lane;
- the one entry lane also plays an important role in the safety perception; this is evident from the positive regression coefficient (+ 0,56) associated with the presence of one entry lane;
- moreover, these users pay less attention to the factor associated with the geometric coherence of the consecutive elements compared to the one associated with individual geometric elements with a lane, as we can see from the negative covariance between the two factors (-0,55).

Ultimately, the users who consider the exit manoeuvre the most dangerous are strongly influenced by roundabout configurations with more than a lane in the exit leg.

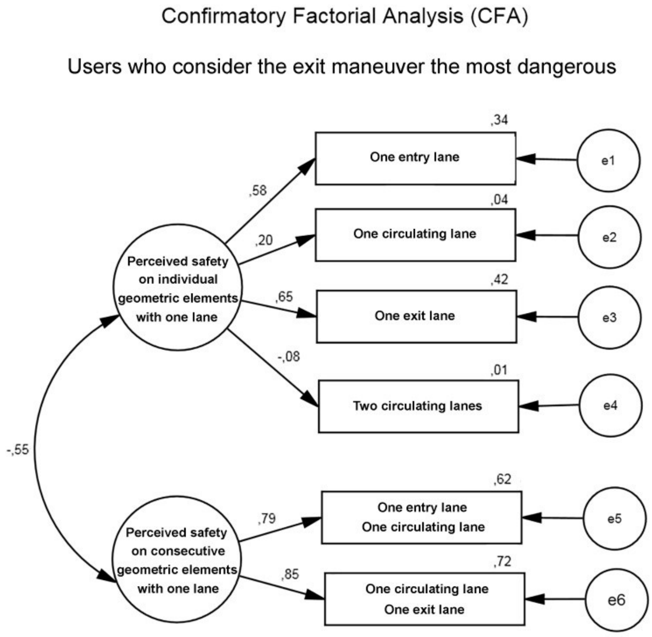

Figure 2.9 - CFA path diagram of perceived safety by users who consider the exit manoeuvre the most dangerous.

2.4 Conclusion

The purpose of this research was to evaluate the roundabout geometric characteristics affecting the safety perception during the typical manoeuvres (entry, circulation, exit). The method of acquisition of opinions was an on-line questionnaire that has generated a very large database containing data from over 1.600 interviews. The final aim was to deduce the influence of roundabout design options on the safety perception, based on the different respondents' driving experiences on roundabouts. It was thus possible to subdivide the sample of respondents into three macro-categories, in relation to their opinions regarding the perceived safety while performing the three possible roundabout manoeuvres (entry, circulation, exit).

Through the combined use of the various statistical analysis techniques based on dimensionality reduction methods (Correspondence Analysis, Cluster Analysis, Exploratory Factor Analysis, Confirmatory Factor Analysis), a Structural Equation Modeling (SEM) was obtained. The SEM items are some of the geometric elements of roundabouts, whose combination determines different geometric roundabout configurations.

The considerations deriving from the final modelling are the following:

- the respondents’ opinions regarding the safety perception of manoeuvres are not preconceived ideas, but they originate from specific safety perceptions due to roundabout geometric configurations;
- the users prefer definitely single lane roundabouts; this is an important confirmation of most results in the literature;
- it was quantified the extent of the relationship between the safety perception of the typical roundabout manoeuvres and the following aspects: a) manoeuvre type, b) geometric characteristics of the roundabouts design elements. This is the innovative aspect of the present research whose results have implications regarding theory, infrastructure and the application of new safety technologies.

It is strongly believed that the results of this study are useful to understand how geometric elements of roundabouts affect the users’ safety perception. Nevertheless, other studies and other analysis are necessary in order to better understand the role of the human factor in the risk perception of road infrastructure, especially of road intersections. The efforts of this research group are being oriented in this direction. The authors believe that, in the near future, additional aspects of the safety perception of roundabouts may be disclosed. This will be useful for an increasing understanding of how the human factor plays a decisive role in conditioning the driving behaviour. Obviously such understanding will also be crucial for the definition of new design criteria and / or for the improvement of the existing ones.

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3. MULTIPLE CORRESPONDENCE ANALYSIS (MCA) FOR THE EVALUATION OF RISK PERCEPTION OF ROUNDABOUTS FOR YOUNG PEOPLE

This chapter investigated the risk perception of roundabouts for young people in order to identify the major factors which influence such perception. A road users survey was developed to obtain young people feedback on roundabouts. Multiple Correspondence Analysis (MCA) was used in order to understand how the young people features, the geometric characteristics and the traffic conditions of roundabouts affect the respondents' risk perception.

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3.1 Introduction

Road users' awareness of potential risks is an important factor in many accidents. Risk perception, i.e. the ability to "read the road" in relation to potentially dangerous situations in the traffic environment, seems to be the only component of driving skills that has been found to be related to accident involvement (Horswill and McKenna, 2004). For many decades road safety researchers have been attempting to explain how people perceive and understand risk (McKenna and Crick, 1991 and 1997; Hull and Christie, 1992; Borowsky et al., 2010; Horswill et al., 2015; Horswill et al., 2016). The reason that risk perception ability has retained interest over the years is because anticipation of hazardous traffic situations is one of the major contributions to driver safety. For example, Horswill et al. (2015) found that drivers who failed a risk-perception test had 25% more active crashes (i.e. crashes in which the driver's vehicle was moving, excluding parking or reversing) in the year following the test. In contrast to most driver education and assessment interventions, risk-perception testing and training have the capability to reduce crash risk (Horswill, 2016). It is acknowledged that human factors may contribute to accident involvement in traffic (Grayson and Maycock, 1988). Based on a study of 2041 traffic accidents, Sabey and Taylor (1980) concluded that human factors were contributing elements in 95% of the accidents. In particular, driving behaviour was identified as the most central of these factors. Driving attitude, which is manifested by driving behaviour, strongly affect the risk perception of drivers (Cheng et al., 2011). Therefore, it is important to understand the aspects affecting the drivers' ability to perceive danger and risk and, thus, affecting their driving behaviour. Human driving behaviour is strongly affected by the road environment, as driving involves complex interactions between the driver and the environment. For example, Lim et al. (2013) found that familiarity with the driving environment facilitated drivers' ability to discriminate risks in a timely manner. Considering the extreme complexity of road networks, the aspects affecting the driving behaviour should be studied with specific regard to the elements of road networks as, for example, the intersections. It is well known that intersections are among the most complex road environments: their geometric configuration, the signs and the markings, the road furniture, the qualitative and quantitative characteristics of traffic, the vehicular conflicts are all elements which weigh the driver workload, a therefore affect the driving behaviour and the risk of accident. Among intersections, roundabouts are the most popular nowadays. Converting junctions to roundabouts has been found to reduce the number of accidents, in particular fatal accidents (Elvik, 2003 and 2017; Persaud, 2001; Vujanić, 2016). Studies of roundabouts in various countries have shown that roundabout can significantly improve functional characteristics (Al-Madan, 2003; Easa and Mehmood, 2006; Ma et al., 2013; Mauro and Cattani, 2012), as well as traffic safety (Bie and Wong, 2008; Chen et al., 2013; Gross et al., 2013).

Several studies have highlighted the safety advantages of roundabouts in urban contexts, although roundabouts do not always guarantee adequate levels of safety for vulnerable users, such as pedestrians and cyclists (Pilko and Šarić, 2018; Lakouari et al., 2018; Pilko et al., 2017; Meneguzzer and Rossi, 2013, Sacchi et al., 2011). Giuffrè and Grana (2013) presents an exploratory analysis aimed at modeling the crash phenomenon for a set of injury crash data of urban roundabouts operating in the road network of Palermo City, Italy.

Engineering design is considered one of the most important factors affecting the efficiency and safety of a roadway system especially for roundabouts, which directly influences the maneuvering behaviour and driver's speed adoption. It was found that at least one geometric factor is responsible for 60% of the total crashes (Montella, 2010). Therefore, geometric design plays a vital role in roundabouts safety. A lot of researchers tried to identify the geometric factors of roundabouts affecting the safety of this type of intersection. Numerous studies focused particularly on the relationship between roundabout geometric design, traffic conditions, and crash rates (Arndt and Troutbeck, 1995; Kennedy et al., 2005; Kim and Choi, 2013; Mahdalova et al., 2013; Anjana and Anjaneyulu, 2015; Kamla et al., 2016; Farag and Hashim, 2017; Daniels et al., 2010; Pecchini et al., 2014; NCHRP, 2010). The results are consistent about the relationship of some variables, such as entry radius, circulatory roadway width, inscribed circle diameter and angle to the next leg, with crash frequency. An increase in the value of entry radius, circulatory roadway width, inscribed circle diameter increases crash frequency. With an increase in angle to the next leg, crash frequency decreases. Geometric variables such as entry width, gradient and central island diameter show instead an inconsistent relationship with crash frequency across different studies. A lot of studies have also suggested some models to optimize the geometric design of roundabouts (e.g. Easa and Mehmood, 2006; Šurdonja et al., 2013). While previous studies have provided valuable information as to the relationship between roundabout geometrical features, traffic conditions and crash rates, to the best of our knowledge, few similar analyses for risk perception of roundabouts have been carried on (e.g. Distefano et al., 2018). Despite the high level of safety recognized for roundabouts, there are several factors influencing the driver behaviour. These factors can cause incorrect behaviors which can degenerate into accidents. Therefore, this study intends to contribute for a better understanding of the factors that affect the risk perception of roundabouts.

Specifically, we will focus on roundabouts risk perception for young people. Young people are more frequently involved in traffic accidents as compared to other age groups (ISTAT, 2017; World Health Organization, 2017). The complexity of young people safety problem is widely acknowledged. It is well established, for example, that young novice drivers play a disproportionately large role in traffic crashes. The risk of a crash for young drivers is higher than for any other age group (Shope, 2006; Williams, 2003). Young people have a higher risk for crash involvement, in part because they are more likely to take risks while driving (Ferguson, 2003; Williams, 2003). They may also be particularly vulnerable to distractions because of their greater propensity to engage in distracting activities (Olsen et al., 2005). Accumulated evidence suggests that experienced drivers possess better risk perception skills than young-inexperienced drivers (e.g., Borowsky et al., 2010; Pollatsek et al., 2006; Wallis and Horswill, 2007). Research has shown that novices are slower in detecting risks, and that they often detect fewer risks than experienced drivers (Underwood et al., 2005). Driving experience, instead, improves drivers’ awareness of potential risks and guides drivers’ eye movements to locations that might embed potential risks (Borowsky et al., 2010). Compared with younger drivers, older drivers have more experience and are more likely to adjust their driving behaviors to suit traffic and road conditions (Begg and Langley, 2001; Bingham and Shope, 2004). It has also been established that young drivers have stronger motivations for risky driving than older drivers do (Hatfield and Fernandes, 2009). Road traffic injuries are the leading cause of death among people aged between 15 and 29 years (World Health Organization, 2017). Therefore, it is necessary to develop some road safety strategies to reduce road traffic injuries especially for young people. A successful road safety strategy should use a combination of education aimed at road users’ behaviour improvements and skills training, along with road environment improvements. For this reason, the final aim of this study is to assess how risk perception of roundabouts for young people varies according to their demographic characteristics (sex, age), to the travel mode, to the geometric characteristics of roundabouts (number of lanes, inscribed circle diameter, circulatory roadway width, presence or absence of the right turn by pass-lane), and to the traffic conditions.

3.2 Methods and variables

3.2.1 Survey and study area

A road user questionnaire was developed in order to collect opinions regarding the risk perception of four existing roundabouts (Figure 3.1) located in different urban contexts in the city of Catania (Italy).

Considering that the final aim of the questionnaire was to evaluate the risk perception of these roundabouts based on the participants driving experience, it was necessary to select participants who had a certain driving experience of the roundabouts studied. Because of this, participants were recruited in person. Specifically, a pre-selection test was used in order to select drivers who knew well the four roundabouts. This pre-selection test contained questions about the knowledge of the four roundabouts and the frequency of use. The drivers who didn’t know the four roundabouts or who used them less than once a week were excluded. Only the drivers who used the roundabouts at least once a week started the questionnaire.

Figure 3.1 - Geometric plan views of the four roundabouts studied.

The questionnaire contained 73 items and consisted of the following four sections:

- Section A: participants reported their age, their gender, the means of transport mainly used and other basic socio-demographic characteristics information;
- Section B: this section included questions regarding the knowledge of how a roundabout works and the overall opinion on roundabouts;
- Section C: this section contained questions about the characteristics of the four roundabouts analysed. Specifically, for each roundabout, participants were asked questions about the geometry, the road furniture, the speed and the traffic.
- Section D: this section regarded the risk perception of the four roundabouts studied. Specifically, for each roundabout, participants were asked questions about the risk perception of the three possible manoeuvres (entry, circulation, exit) and about the overall risk perception.

Figure 3.2 shows the questionnaire structure.

The four roundabouts studied were chosen in order to have a certain heterogeneity of geometric-constructive characteristics (inscribed circle diameter, presence or absence of the double entry lane or the double circulatory roadway, legs slope, visibility, etc.) and of operational conditions (traffic flows, presence of vulnerable users, etc.). The geometric characteristics of the four roundabouts were obtained from Google Maps. Table 3.1 shows the geometric features of the selected roundabouts. All roundabouts have four-arms and they are classified according to the number of lanes per approach (one or two lanes), the presence or absence of right-turn bypass lane, the inscribed circle diameter and the circulatory roadway width.

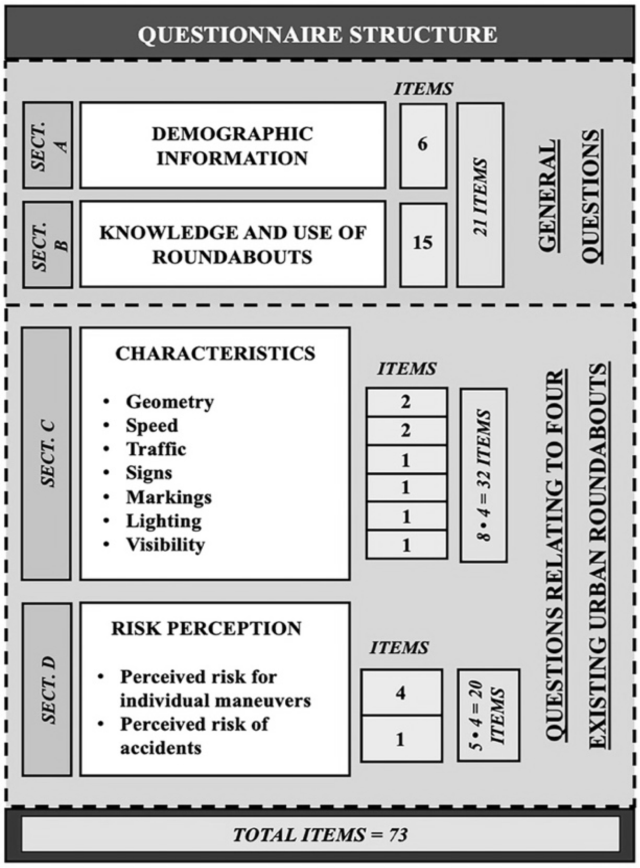

Figure 3.2 - Questionnaire structure.

Table 3.1 - Roundabouts geometric characteristics.

	Entry (En)	*Exit (Ex)*	*Right turn bypass-lane*	*Inscribed circle diameter (D)*	*Circulatory roadway width (C)*
ROUNDABOUT A					
Approach A1	9,30 m (2 lanes)	6,90 m (2 lanes)	No	70,00 m	9,00 m (2 lanes)
Approach A2	4,40 m (1 lane)	5,80 m (1 lane)	Yes		
Approach A3	8,00 m (2 lanes)	7,05 m (2 lanes)	Yes		
Approach A4	7,70 m (2 lanes)	8,90 m (2 lanes)	Yes		
ROUNDABOUT B					
	Entry (En)	*Exit (Ex)*	*Right turn bypass-lane*	*Inscribed circle diameter (D)*	*Circulatory roadway width (C)*
Approach B1	4,40 m (1 lane)	6,15 m (1 lane)	Yes	32,00 m	6,50 m (single lane)
Approach B2	5,80 m (1 lane)	4,45 m (1 lane)	No		
Approach B3	4,70 m (1 lane)	6,60 m (1 lane)	Yes		
Approach B4	5,90 m (1 lane)	4,15 m (1 lane)	No		
ROUNDABOUT C					
	Entry (En)	*Exit (Ex)*	*Right turn bypass-lane*	*Inscribed circle diameter (D)*	*Circulatory roadway width (C)*
Approach C1	5,55 m (2 lanes)	6,75 m (2 lanes)	No	41,00 m	7,85 m (double lane)
Approach C2	8,30 m (2 lanes)	7,00 m (2 lanes)	No		
Approach C3	5,25 m (1 lane)	4,95 m (1 lane)	No		
Approach C4	8,10 m (2 lanes)	5,66 m (2 lanes)	No		
Note: This roundabout also has a fifth approach. However, it was not considered in the analysis because it is one-way and it is characterized by extremely low vehicular flows.					
ROUNDABOUT D					
	Entry (En)	*Exit (Ex)*	*Right turn bypass-lane*	*Inscribed circle diameter (D)*	*Circulatory roadway width (C)*
Approach D1	4,45 m (1 lane)	3,20 m (1 lane)	No	33,00 m	7,10 m (single lane)
Approach D2	4,50 m (1 lane)	4,15 m (1 lane)	No		
Approach D3	5,60 m (1 lane)	4,75 m (1 lane)	No		
Approach D4	4,25 m (1 lane)	5,00 m (1 lane)	No		

As for the operational conditions, it was defined an easy-understanding criterion in order to obtain from the respondents' opinions regarding the traffic conditions on the roundabouts studied. The final aim was to obtain an opinion regarding the traffic conditions on the basis of the driving situations dealt with in the phases of approach and entry on the circulatory roadway. Because of this, three types of traffic conditions were considered: low, medium and high. The "low traffic" means that the traffic conditions are not affecting significantly the achievement of the yield line on the entry lane and the entry on the circulatory roadway. The "medium traffic" means that the traffic conditions create some delay in the achievement of the yield line on the entry lane and in the entry on the circulatory roadway. The “high traffic” is associated with significant delays during the approach (e.g. slow queue dissipation speed) and/or during the entry on the circulatory roadway (e.g. difficulties in finding the gap to enter the circulatory roadway).

The concepts of high, medium and low traffic were considered questionable. Because of this, "surrogate" indicators were adopted. Therefore, a criterion based on the lost-time t associated to the entry on the roundabout was chosen. The 1-minute time interval was considered as time base for the lost-time because the 1-minute interval is easily identified by drivers on the base of their driving experience. A lost-time of more than 1 minute is always perceived as an uncomfortable situation, near to the traffic congestion. The lost-time of half-minute (or less) is considered to be a fluid traffic condition. Thus, a question related to the lost-time t associated to the entry on the roundabout was included in the questionnaire. The possible answers were three: 1) less than half minute; 2) between half minute and one minute; 3) more than one minute. Based on this, they were identified low ($t < 30$ sec), medium (30 sec $< t < 60$ sec) and high ($t > 60$ sec) traffic flows for each of the four roundabouts. The choice of the base value of 1 minute is consistent with the indications of the Highway Capacity Manual. Table 3.2 shows the average control delays associated to the corresponding level of services for roundabouts according to the Highway Capacity Manual (2010). These values are associated with three levels of satisfaction: 1) high level of satisfaction (LOS from A to C); 2) average satisfaction level (LOS from D to E); 3) low degree of satisfaction (LOS = F).

Table 3.2 - Level of Service Criteria for Roundabouts

Level of service	*Average Control Delay (seconds/vehicle)*
A	0 – 10
B	> 10 – 15
C	> 15 – 25
D	> 25 – 35
E	> 35 – 50
F	> 50

Source: Highway Capacity Manual 2010, Transportation Research Board, 2010

3.2.2 Participants and procedure

In order to obtain young drivers’ opinion, the survey was conducted at the University Campus of Catania over a 3-month period. Participants were briefed of the nature and time required to participate in the study prior to commencement. After their consent was obtained, the questionnaire started. It was decided to question directly the participants, instead of left them alone with the questionnaire, in order to provide visual aids and detailed explanations and clarifications. Each survey lasted approximatively 25 minutes. The interviewer asked to the respondent the questions with the aid of a tablet. The digital form of the survey was created with Google Forms Software. This allowed to record the data in digital format and to speed up the data collection phase and the post-processing phase. The Section C and Section D questions (related to the four roundabouts located in Catania) were answered while showing to the respondent a photographic catalogue in digital form. The photographic catalogue was created using Google images representing each roundabout from different perspectives.

The total sample comprised 977 students (629 males and 348 females) between the ages of 18 and 35 years. Participants who didn't complete the questionnaire or who didn’t answer well the questions regarding the knowledge of how a roundabout work (Section B of the questionnaire) were excluded. The respondents excluded were 5% of the sample. The final sample was 928 participants. All participants included in the study had a driving license. Participants were assured of anonymity and confidentiality. The majority of respondents (around 84%) were below the age of 25; only 16,38% were aged between 26 and 35 years. As for sex, males were more numerous than females (64,66% of the sample was made up by men and 35,34% were women). The travel mode most frequently used was the car (73,28%). About 14% of the sample were motorcyclists, while pedestrians were about 13%. Participants’ characteristics are shown in Table 3.3.

Table 3.3 - Characteristics of survey respondents.

Category	*Number*	*Percent*
Age		
18-21	352	37,93 %
22-25	424	45,69 %
26-35	152	16,38 %
Total	928	100,00 %
Sex		
Male	600	64,66 %
Female	328	35,34 %
Total	928	100,00 %
Travel *mode*		
Car	680	73,28 %
Motorcycle	128	13,79 %
Pedestrian	120	12,93 %
Total	928	100,00 %

3.2.3 Analytical method

Starting from the survey data, the final aim of this study was to analyse the factors influencing the roundabouts risk perception for young people. Multiple Correspondence Analysis (MCA) was chosen to conduct this analysis.

MCA is part of a family of descriptive methods that reveal patterning in complex datasets. Specifically, MCA is used to represent and model datasets as “clouds” of points in a multidimensional Euclidean space; this means that it is distinctive in describing the patterns geometrically by locating each variable/unit of analysis as a point in a low-dimensional space. The results are interpreted on the basis of the relative positions of the points and their distribution along the dimensions; as categories become more similar in distribution, the closer (distance between points) they are represented in space. Although it is mainly used as an exploratory technique, it can be a particularly powerful one as it “uncovers” groupings of variable categories in the dimensional spaces, providing key insights on relationships between categories (i.e., multivariate treatment of the data through simultaneous consideration of multiple categorical variables), without needing to meet assumptions requirements such as those required in other techniques widely used to analyse categorical data (e.g., Chi-square analysis, G-statistics, and ratio test). The use of MCA is, thus, particularly relevant in studies where a large amount of qualitative data is collected, often in pair with quantitative data, and where qualitative variables can become sub optimized in the data analysis. MCA plot are a better way of presenting information graphically and one can interpret them by examining the distribution of variable groupings in space. Points (categories) that are close to the mean are plotted near the MCA plot's origin and those that are more distant are plotted farther away. Categories with a similar distribution are near one another in the map as groups, while those with different distributions stay farther apart. In a two-dimensional graphical display of the data, categories sharing similar characteristics are located close together, forming point clouds. MCA is performed on an I × Q indicator matrix in which I is the set of i individual records, runway excursion accidents, and Q is the set of categories of all variables, characteristic features. Given this, the component in the cell (i, q) consists of the individual record i and category j. Associated categories in MCA are placed close together in a Euclidean space, leading clouds, or a combination of points that have similar distributions. Notably, MCA produces point clouds, which are usually defined by two-dimensional graphs.

Suppose, the number of individual records associated with category k is denoted by nk (with nk >0), where fk=nk/n is the relative frequency of individuals who are associated with category k. The values of fk will generate a row profile. The distance between two individual records is created

by the variables for which both have different categories. Suppose that for variable q, individual record i contains category k and individual record i' contains category k' which is different from k. The squared distance between individual records i and i' for variable q is defined by Eq (1):

$$d_q^2(i,i') = \frac{1}{f_k} + \frac{1}{f_{k'}} \quad (1)$$

Denoting Q as the number of variables, the overall squared distance between i and i' is defined by Eq. (2):

$$d^2(i,i') = \frac{1}{Q}\sum_{q\in Q} d_q^2\,(i,i') \quad (2)$$

The cloud of categories is a weighted cloud of K points (by category k, a point denoted by Mk with weight nk is represented). For each variable, the sum of the weights of category points is n, hence for the whole set K the sum is nQ.

If nkk' indicates the number of individual records having both categories (k and k'), then the squared distance between Mk and Mk' is defined by Eq (3):

$$(M^k M^{k'})^2 = \frac{n_k + n_{k'} - 2n_{kk'}}{n_k n_{k'}/n} \quad (3)$$

The numerator is the number of individual records associated with either k or k'.

In this study, MCA was determined to be the better choice for data processing. MCA was chosen mainly because it allows to perform efficient dimensionality reductions and to compile results into easy-to-read plots. The research team used statistical software SPSS version 24.0 to perform the MCA technique in order to examine how risk perception in roundabouts by young people varies with the characteristics of the respondents and with the geometric characteristics and the traffic conditions of roundabouts.

3.2.4 Variables

The variables used in MCA concerned the socio-demographic characteristics of the respondents (gender, age, travel mode), the geometric characteristics of roundabouts (number of lanes, inscribed circle diameter, circulatory roadway width and right turn bypass lane), the traffic conditions of roundabouts and the risk of accidents perceived by the respondents in the analysed roundabouts. Specifically, the variable associated with the risk of accident perceived in the four roundabouts studied (Section D of the questionnaire), is divided into three categories: high, medium and low. Figure 3.3 provides data related to the risk of accidents perceived by the respondents in the four roundabouts.

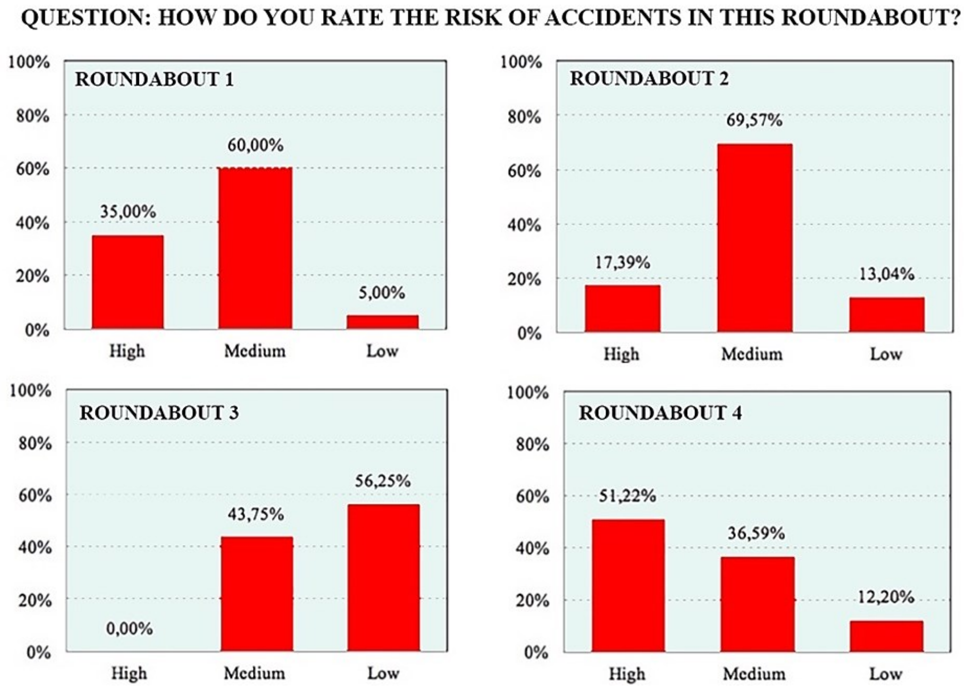

Figure 3.3 - Summary of risk of accidents perceived in the four roundabouts.

Table 3.4 shows the 9 variables individuated and all the categories defined for each variable.

Table 3.4 - Variables and related categories

Variable	*Categories*	*Code*
Gender	Male	G1
	Female	G2
Age	18-21	A1
	22-25	A2
	26-35	A3
Travel mode	Car	M1
	Motorcycle	M2
	Pedestrian	M3
Number of lanes	1	L1
	2	L2
Inscribed circle diameter (D)	$D \leq 40$ m	D1
	40 m $\leq D \leq 60$ m	D2
	$D \geq 60$ m	D3
Circulatory roadway width (W)	$W \leq 7$ m	W1
	7 m $\leq W \leq 9$ m	W2
	$W \geq 9$ m	W3
Right-turn bypass lane	Present	B1
	Absent	B2
Traffic flow	Low	T1
	Medium	T2
	High	T3
Risk of accidents perceived	Low	R1
	Medium	R2
	High	R3

3.3 Results and discussion

Multiple Correspondence Analysis was applied to the data collected. To define the correspondence between the categories of each variable, the statistical software SPSS version 24 was used. Output of MCA is a two-dimensional graph. The MCA graphical representations help simplify the process of interpreting the relationships among variables.

The model resulted in two dimensions with eigenvalues >1, explaining 64.17 per cent of the variance (Table 3.5). Figure 3.4 illustrates the MCA plot. The MCA plot shows the distribution of the coordinates of all categories. This plot gives us an idea of the variable categories' positions on the two-dimensional space based on their eigenvalues. In this study, in order to easily comment on the results of Multiple Correspondence Analysis, we wanted to proceed with a two-step discussion of the influence on the risk perceived by young users due to the various variables considered. First, we analysed the socio-demographic variables (age, gender, travel mode) and later, the geometric and traffic variables (number of lanes, inscribed circle diameter, circulatory roadway width and right turn bypass lane).

Table 3.5 - Model summary resulting from the MCA.

Dimension	*Cronbach's Alpha*	*Variance accounted for total (Eigenvalue)*	*Inertia*	*% of Variance*
1	0.788	3.343	0.371	37.142
2	0.662	2.432	0.270	27.024
Total		5.775	0.642	64,166
Mean	0.735[a]	2.887	0.321	32.083

[a] Mean Cronbach's Alpha is based on the mean Eigenvalue.

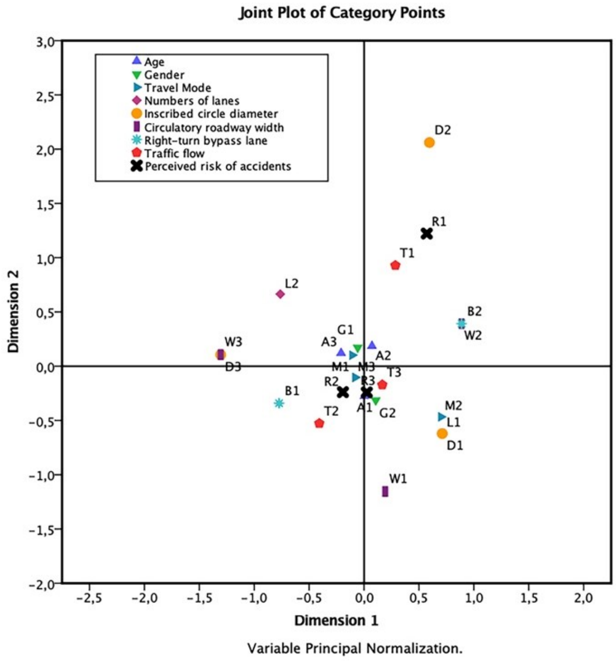

Figure 3.4 - MCA Plot - All categories.

Therefore, starting from the initial MCA plot, two MCA plots were generated: a) the MCA plot illustrated in Figure 3.5 shows the influence of the socio-demographic variables on risk; b) the MCA plot illustrated in Figure 3.6 describes instead how the geometric and traffic variables influence the risk perceived by young people using the roundabouts.

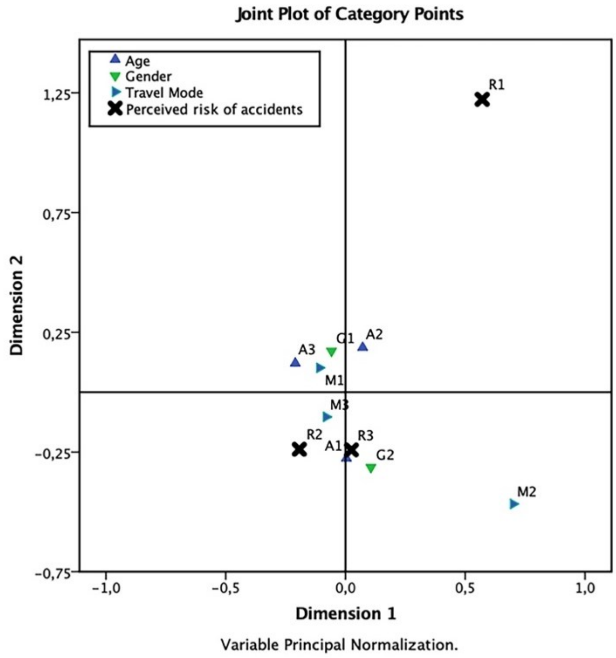

Figure 3.5 - MCA Plot – Categories: a) socio-demographic characteristics; b) perceived risk.

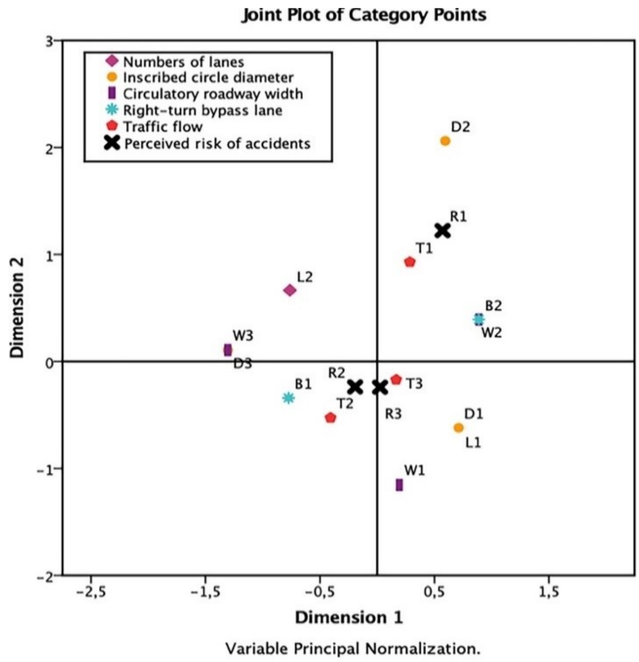

Figure 3.6 - MCA Plot - Categories: a) geometric characteristics; b) traffic conditions; c) perceived risk.

3.3.1 *Risk perceived by young users on roundabouts: influence of socio-demographic variables*

The MCA plot illustrated in Figure 3.5 shows the distribution of the coordinates of all the categories related to the socio-demographic variables and the perceived risk.

First of all, we observe that the two categories representing the greatest risk perception (medium and high risk, i.e. R2 and R3) are associated with two points of the MCA plot that are very close to each other and very close to the origin of the axes. This shows that most of the young respondents always show a not negligible perception of risk in the roundabout.

We must also note that the age of respondents has not a significant influence on the risk perception of roundabouts. Indeed, the points relating to the three categories associated with the "age" variable are all concentrated at the origin of the MCA plot axes. This is probably due to the fact that all respondents are young and so there are not great differences among the three groups considered (18-21, 22-25 and 26-35 years-old).

Also, the gender has not a significant influence on risk perceptions of roundabouts. Females perceive a slightly higher risk than males. Indeed, the two categories G1, G2, although represented by diametrically opposed points in the MCA plot, are both very close to the origin of the axes. The "women" category is close to the "High Risk" category, while the men category is closer to the "Medium Risk" category. These findings support previous research that has shown no difference in roundabouts public opinion with respect to gender (Retting et al., 2002; Retting et al., 2006; Retting et al., 2007).

The travel mode shows interesting results as for the different risk perception among users: pedestrian perceive roundabouts more dangerous compared to drivers and motorcyclists. Indeed, the point of the MCA plot representing the “pedestrian” category is very close to the R3 category (High Risk). The category "motorcyclists" is represented in the MCA plot from a point further away than those associated with the other two categories related to the "travel mode" variable, but, in any case, closer to the risk category R3. The motorcyclists, therefore, are users who perceive a high level of risk in the roundabouts. This is similar to findings from other studies (Hydén and Várhelyi, 2000; Savolainen et al., 2012).

3.3.2 *Risk perceived by young users on roundabouts: influence of geometric and traffic variables*

The MCA plot illustrated in Figure 3.6 shows the distribution of the coordinates of all the categories related to the geometric and traffic characteristics of the roundabouts and to the perceived risk. In this study, three significant cloud combinations were chosen (Figure 3.7). Each of the combinations identified groups the categories of the variables that are most likely to condition the risk perceived by young users.

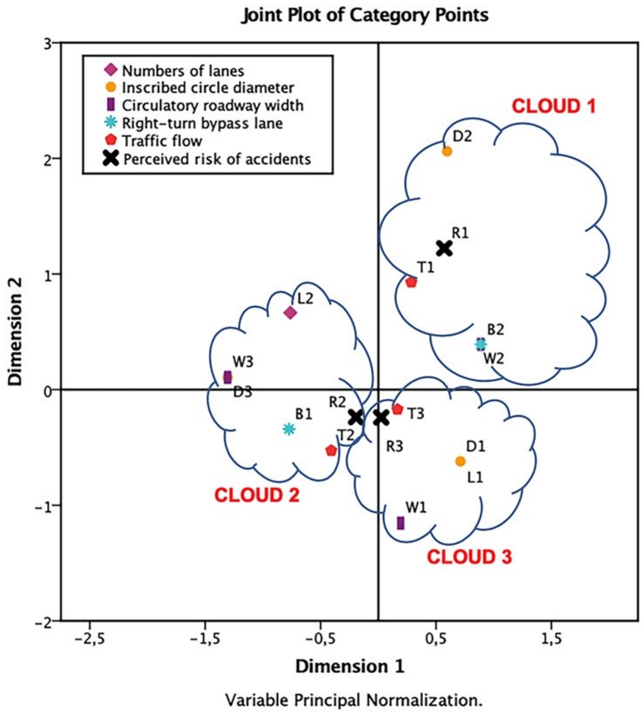

Figure 3.7 - MCA Plot with cloud combinations – Categories: a) geometric characteristics; b) traffic conditions; c) perceived risk.

In particular:

- Combination Cloud 1 combines five categories: Low Risk; Inscribed circle diameter: 40 m ≤ D ≤ 60 m; Circulatory roadway width: 7 m ≤ W ≤ 9 m; Right-turn bypass lane: absent; Traffic flow: low;
- Combination Cloud 2 combines six categories: Medium Risk; Number of lanes: 2; Inscribed circle diameter: D ≥ 60 m; Circulatory roadway width: W ≥ 9 m; Right-turn bypass lane: present; Traffic flow: medium;

- Combination Cloud 3 combines five categories: High Risk; Number of lanes: 1; Inscribed circle diameter: D ≤ 40 m; Circulatory roadway width: W ≤ 7 m; Traffic flow: high.

The geometric parameters associated with the overall and transversal dimensions of the roundabouts (i.e. diameter and width of the circulatory roadway), are perceived as dangerous both in the case of "configurations of minimum dimensions", i.e. D ≤ 40 m and W ≤ 7 m (High Risk), which in the case of "configurations of maximum dimensions", i.e. D ≥ 60 m and W ≥ 9 m (Medium Risk). In the first case (small roundabouts), young people probably perceive the danger of being involved in road accidents resulting from those operating conditions in which, also because of the high vehicular flows, the vehicles are forced to move in reduced spaces without maintaining the appropriate safety distances. In the second case (large roundabouts), there is a significant perception of the danger because the vehicles have too large spaces available that can also encourage hazardous or irregular manoeuvres by other users.

As regards the presence of one or two lanes on the geometric elements of the roundabouts, it was found that young people perceive single-lane roundabouts more dangerous than double-lane ones. It should however be noted that the two categories (L1 and L2) associated with this variable are both equidistant from the centre of the MCA plot and almost equidistant from the two categories R2 and R3 representative of medium and high risk conditions. It can be stated, therefore, that the variable "number of lanes" is not the most influential in the perception of the risk of accidents by young people; the sensation of risk seems to be directly linked to the fact of having to enter the circulatory roadway, regardless of whether the entry to the roundabout is organized with one or two lanes.

The presence of the right turn-bypass lane influences the perceived risk, although it does not lead to the perception of the highest risk in the young respondents. The respondents perceive a low risk of accidents in roundabouts without right turn-bypass lane and a medium risk in roundabouts with right turn-bypass lane.

Finally, traffic conditions strongly affect the risk of accident perceived in roundabouts. It is clear that risk perception grows with traffic congestion. In fact, as evidenced by the position of the T1, T2 and T3 categories in the MCA plot, the fluid traffic conditions are perceived at low risk, the medium ones at medium risk and those of congested traffic at high risk. These findings are consistent with previous studies regarding the relationship between roundabout geometric design, traffic conditions, and crash rates. A lot of researches showed, for example, that variations in crash rates at roundabouts are mainly driven by the traffic (e.g. Daniels et al., 2010; Pecchini et al., 2014; NCHRP, 2010) and that an increase in the circulatory roadway width increases the total crashes in roundabouts (e.g. NCHRP, 2010; Farag and Hashim, 2017).

3.3.3 Definition of a ranking of roundabouts in relation to perceived risk

The results of the MCA analysis applied to the collected data showed that roundabouts risk perception for young people is weakly affected by the socio-demographic characteristics, and it arises mainly from geometric characteristics and traffic conditions affecting the safety offered to the different type of users (drivers, motorcyclists and pedestrian).

With the aim of a better understanding of the role of these variables in the roundabouts risk perception for young people, the “Discrimination Measures” obtained by the MCA analysis (Figure 3.8) were used to determine the Weighting Factors (WFi) of the variables associated with the geometric and traffic characteristics; this is to quantify the influence of these variables on the “Perceived Risk of Accidents” variable.

From the diagram shown in Figure 3.8 it is even more evident that the traffic flow is that which contributes the most to influencing the risk perceived by young users. Conversely, the diameter of the roundabout and the width of the circulatory roadway have the least influence on the perception of risk.

The Weighting Factors (WFi) deduced from Figure 3.8 are shown in Table 3.6.

Table 3.6 – Weighting Factors of the variables associated with the geometric and traffic characteristics.

	Number of lanes	*Inscribed circle diameter (D)*	*Circulatory roadway width (W)*	*Right-turn bypass lane*	*Traffic flow*
Weighting Factors (WF_i)	*2.2*	*1.0*	*1.4*	*2.90*	*21.3*

Furthermore, from the MCA plot, the distances of all the categories associated with the geometric and traffic variables from the three risk categories (Low, Medium, High) were evaluated. Table 3.7 shows these distances ($Dist_i$) using conventionally:

- the number 1, to indicate the distance of the geometric or traffic category from the furthest risk category;
- the number 3, to indicate the distance of the geometric or traffic category from the nearest risk category;

- the number 2, to indicate the distance of the geometric or traffic category from the risk category other than those defined in the previous points.

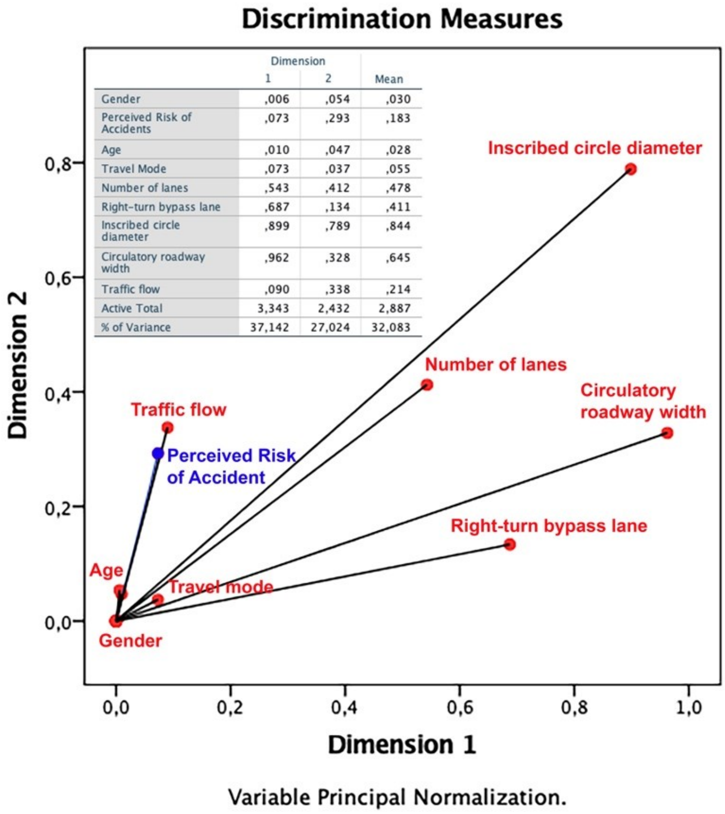

Figure 3.8 - Discrimination measures.

Table 3.7 - Conventional distances of geometrical and traffic categories from risk categories.

	Conventional distances ($Dist_i$)												
	Number of lanes		*Inscribed circle diameter (D)*			*Circulatory roadway width (W)*			*Right-turn bypass lane*		*Traffic flow*		
Perceived risk of accidents	L1	L2	D1	D2	D3	W1	W2	W3	B1	B2	T1	T2	T3
Low (R1)	1	1	1	3	1	1	3	1	1	3	3	1	1
Medium (R2)	2	3	2	1	3	2	1	3	3	1	1	3	2
High (R3)	3	2	3	2	2	3	2	2	2	2	2	2	3

The level of risk perceived for a specific configuration of roundabout was defined by the weighted average, using the Weighting Factors (WF_i), of the distances ($Dist_i$)

associated with the geometrical and traffic categories that fully define the configuration of the analysed roundabout. Dividing all the values of the risk level to the minimum value, that is the one associated with the perceived less dangerous configuration by the young respondents, the “Relative Risk Levels (RRL)” shown in Table 3.8 were obtained. The combination of the geometric variables (number of lanes, inscribed circle diameter, circulatory roadway width and right turn-bypass lane) and of the traffic conditions gave rise to 11 different configurations of roundabouts (configuration A to K in Table 3.8). In order to find the combinations of geometric factors and traffic conditions in roundabouts preferred by young users, a ranking of the 11 configurations of roundabouts was defined. The ranking was defined based on the RRL values for the 11 configurations of roundabouts. The configurations were ordered by decreasing order starting from the highest value of the Relative Risk Level.

Table 3.8 - Relative Risk Levels (RRL) values for 11 configurations of roundabouts.

	N. of lanes	*Right turn-bypass lane*	*Circulatory roadway width*	*Inscribed circle diameter*	*Traffic flow*	*Relative Risk Level*
Configuration A	1	Yes	W ≤ 7 m	D ≤ 40 m	Low	1,006
Configuration B	1	Yes	W ≤ 7 m	D ≤ 40 m	Medium	1,203
Configuration C	1	Yes	W ≤ 7 m	D ≤ 40 m	High	1,360
Configuration D	1	No	7 m ≤ W ≤ 9 m	40 m ≤ D ≤ 60 m	Low	1,003
Configuration E	1	No	7 m ≤ W ≤ 9 m	40 m ≤ D ≤ 60 m	Medium	1,199
Configuration F	1	No	7 m ≤ W ≤ 9 m	40 m ≤ D ≤ 60 m	High	1,357
Configuration G	2	Yes	W ≥ 9 m	D ≥ 60 m	Low	1,001
Configuration H	2	Yes	W ≥ 9 m	D ≥ 60 m	Medium	1,198
Configuration I	2	Yes	W ≥ 9 m	D ≥ 60 m	High	1,355
Configuration J	2	No	7 m ≤ W ≤ 9 m	40 m ≤ D ≤ 60 m	Low	1,000
Configuration K	2	No	7 m ≤ W ≤ 9 m	40 m ≤ D ≤ 60 m	Medium	1,197

The radar chart in Figure 3.9 provide a graphical representation of this ranking: it shows the risk perceived for the 11 configurations of roundabouts in decreasing order, from the one perceived as the most dangerous to the one perceived as the safest. Therefore, in this chart the 11 configurations of roundabouts analysed were placed in descending order according to their level of risk perceived, clockwise starting from the most dangerous at the top centre. The configurations have been exemplified through schematic drawings representing their geometric characteristics and traffic flows, in order to have an immediate view of them. In the different drawings, high traffic flows are represented with red cars, medium traffic flows are represented with blue cars and low traffic flows are represented with green cars.

From Figure 3.9 it can be immediately observed that the variable mostly affecting the risk perception is the traffic: indeed, the configurations perceived to be the most dangerous (i.e., configurations C, F and I) despite having different geometric characteristics, are exactly those with high traffic flows. Conversely, the configurations perceived as the safest (i.e., configurations A, D, G and J) are precisely those with the lowest traffic flows. The configurations B, E, H and K, positioned in the radar chart between those perceived as the most dangerous and those considered to be the safest, are all those characterized by medium traffic flows. Therefore, the radar chart shows three groups of roundabouts characterized, in order of decreasing perceived risk, by high, medium and low traffic conditions.

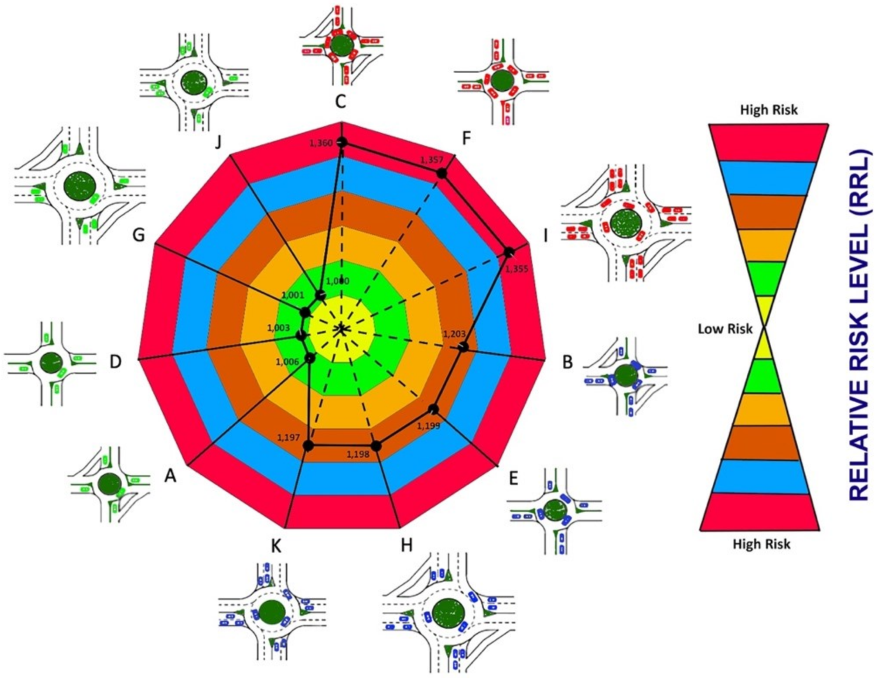

Figure 3.9 - Risk perception radar chart for the 11 configurations of roundabouts.

The three groups of roundabouts, highlighted by the radar chart, therefore are homogeneous from the point of view of traffic conditions, but not homogeneous as regards the geometric characteristics of the roundabouts. With regard to the geometric parameters, the following considerations have therefore been deduced, valid for each of the three groups mentioned above:

- the greatest risk is perceived on small roundabouts, with the single lane on the legs and on the circulatory roadway;
- the minor risk is perceived on medium / large roundabouts, with the double lane on the legs and on the circulatory roadway;
- the right turn-bypass lane seems to have little influence on the perception of risk. Indeed, in the roundabouts included in each of the three analysed groups, this lane is alternately present and absent and, therefore, there is no clear influence of this geometric element on the level of risk perceived by young users.

3.4 Conclusions

This study investigated the risk perception of roundabouts for young people in order to identify the major factors which influence such perception. A road users survey was developed to obtain young people feedback on roundabouts. Multiple Correspondence Analysis (MCA) was used in order to understand how the young people features, the geometric characteristics and the traffic conditions of roundabouts affect the respondents' risk perception. Finally, a risk perception scale was defined for the configurations of roundabouts identified. From the radar diagram representative of the risk perception scale for the configurations of roundabouts related to the geometric characteristics and to the traffic flow considered, the following results were found:

1. traffic conditions strongly affect risk perception of roundabouts. On a sample of 11 configurations of roundabouts, all three perceived as the most dangerous are characterized by high traffic flows;
2. the roundabouts with small circulatory roadway (smaller than 7 m), with a diameter less than 40 m and with one lane on the legs and on the circulatory roadway are generally perceived as more dangerous than those with a medium/large circulatory roadway (larger than 7 m), with a diameter longer than 40 m and with two lanes n the legs and on the circulatory roadway;
3. the right-turn bypass lane affects the respondents risk perception, but not in a clear and unambiguous manner.

It is well known that roundabouts are safer than other forms of intersections. However, driving behaviour is continuously changing. It is therefore important to understand how roundabouts design could be improved to make them safer for their actual users. The authors believe that the results presented on this paper provide updated findings which may be useful to improve roundabouts design. The results of this study are based on a certain sample of young people and on certain configurations of roundabouts. Further studies will focus on overcoming the above-mentioned limitations. Sample sizes could be larger and other several geometric configurations of roundabouts could be considered. The results presented in this research along with future extensions would provide a complete comprehension of the young drivers' behaviour for the optimum design of roundabouts. This type of study could also be extended to other categories of users (such as the elderly, the pedestrians, the motorcyclists, etc.) in order to understand the roundabouts risk perception for different type of users.

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4. HOME-SCHOOL TRAVEL: ANALYSIS OF FACTORS AFFECTING ITALIAN PARENTS' MODE CHOICE

This chapter presents a study related to the safety of children. The approach used is the evaluation of children's safety perception of home-school paths based on their parents' opinions. In order to develop this analysis, the data collected from a survey conducted in front of 9 schools (kindergartens and primary schools) in Catania were used. A path analysis was carried out to analyse these data. The methodology used allowed to understand which elements favour parents' willingness to "trust" safe home-school paths in order to let their children walk to school. At the same time the data of the survey were used to evaluate parents' safety perception of the existing home-school paths and understand a correlation between the choice of walking or of driving to school.

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4.1 Introduction

Children are vulnerable road users in the community travelling to school, parks and other neighbourhood destinations. Limited cognitive, behavioural and physical abilities make children more susceptible to injuries where infrastructure and interventions are not designed to promote road safety [1]. Pedestrian injury is a major hazard to the health of children in most developed countries. Pedestrian accidents are one of the first causes of injury-related deaths and hospitalizations among children aged 5 to 14 in industrialized countries. Accidents in Italy are the main cause of death and disability in the ages after the first year of life, and most of the fatal ones (about 50% of the total) are on the road [2].

According to the data from the Italian National Institute of Statistics [2], despite the EU strategic goal of reducing the number of road casualties by 50% from 2010 to 2020, in Italy the number of child pedestrian crash fatalities from 0 to 14 years of age has not decreased since 2010 to the present day. The age groups with the highest number of deaths are 0-5 years old and 11-14 years old. Even the number of child pedestrian crash injuries from 0 to 14 years in Italy has remained almost stable since 2010. In this case, the age group with the highest number of injuries is 11-14 years-old. It is also interesting to compare the number of child injuries and fatalities in Italy since 2010 to the present day in every type of road accident (children occupants of motor vehicles, child cyclists and child pedestrians) and the number of child pedestrian injuries and fatalities in the same period of time. While the number of child fatalities in every type of road accident has overall decreased since 2010 to the present date, the number of child pedestrian fatalities is almost stable. As for injuries, both the number of child injuries in every type of road accident and the number of child pedestrian injuries is almost stable.

In Italy, only one third of children walks to school. 33.2% of them is up to 5 years of age and 41.7% of them is between 11 and 13 years of age [3]. According to a research by the Policy Studies Institute of London [4], children who go to elementary school on their own are only 7% in Italy, compared to 41% in Great Britain and 40% in Germany.

Although children's travel mode decisions are governed by a complex set of factors, parents are considered as 'gatekeepers' of children's travel mode decisions [5]. In order to investigate Italian parents' opinion regarding their children travel to school, a survey was developed. Participant were recruited in person in order to select appropriate participants and in order to provide visual aids and explanations. This methodology of interviewing participants was already used by the authors for previous studies [6]. The main aim of this study was to identify and to analyse the factors that affect Italian parents' propensity to drive their children to school. This is a widespread habit in Italy, so the analysis of these factors can be useful both for the information campaigns aimed at encouraging parents to use alternative means of transport and for the identification of traffic calming measures to be realized on the home-school paths. This would be certainly helpful in order to encourage children to walk to school on their own in conditions of maximum safety. The relationship among the factors that lead parents to choose to drive their children to school rather than walking was investigated. Moreover, the availability of Italian parents to let their children walk to school, if the home-school path was absolutely safe, was analysed. Here again, the factors affecting this availability were analysed in order to identify the safety measures to be implemented in order to encourage parents to let their children walk to school. In the end, the two analyses of this study were related to each other in order to understand if the safety measures that positively affect the parents' availability to let their children walk to school, could also discourage the use of cars.

4.2 An overview of the literature

A high percentage (about 23%) of road accidents involving children occur on the home-school paths [7,8]. The home-school path is indeed the first and most important use of the urban areas for children since they have to travel it daily. Children are exposed to high crash risk near schools [9]. This highlights the need to improve road safety for children, especially for child pedestrians on the home-school paths.

Pedestrian injuries in school-aged children can be reduced by implementing Safe School zone projects [10-12]. Planning school neighbourhoods focusing on the needs of child pedestrians and child cyclists by designing accessible schools with low traffic exposure, sidewalks and drop off zones at some distance from the school would increase the potential for walking and cycling to school, and would decrease the need for children to be chauffeured [13]. Moreover, it could decrease the risk of establishing a pattern of car dependence in children that carries over into adolescence and adulthood [14].

In order to guarantee road safety for children going to school, informational strategies and infrastructural interventions should be adopted. Information strategies can be implemented involving both children and their parents. Road education courses, already starting from kindergartens, are an effective policy aimed at educating children on the rules of road behaviour [15,16]. Parents, on the other hand, through information campaigns can be sensitized towards two main objectives: 1) to keep particularly prudent driving behaviour (e.g., reduced speed), 2) to become aware that a traffic accident between a vehicle and a pedestrian always involves serious consequences for children who are victims of accidents. Reference [17] showed that such campaigns are important to raise awareness, but that they should be supplemented with complementary activities in order to be really effective. From a safety point of view, a higher traffic volume could also be associated with an increased risk of pedestrian injury or death [18,19]. Reference [20] showed that a higher number of vehicles could produce an unpleasant walking environment. Reference [21] demonstrated the effectiveness of traffic calming measures in accident prevention on home-school paths. Among infrastructural interventions, one of the most efficient is the “Safe roads to school program” that uses traffic calming measures to achieve a dual objective: 1) the reduction of speed of vehicles on home-school paths; 2) the reduction of vehicle flows in areas adjacent to schools.

Both information campaigns and infrastructural interventions are therefore aimed at reducing the probability of vehicle-child conflicts that can degenerate into accidents with very serious consequences. Considering that the number of children on home-school paths is high, one possibility to reduce the probability of a child-vehicle accident could be reducing the frequency of motor vehicles. Reference [22] showed that the “Safe Routes to School program” was associated with an increase in walking and biking. They demonstrated in particular that the education program with additional improvements such as sidewalks, crosswalks, covered bike parking was associated with an increase in walking and biking of 5–20 percentage points.

Previous studies also highlighted the importance of including parents’ perceptions in analysing children’s travel pattern. Parents determine to a large extent the mode choice of school aged children. In the search for crash risk factors of child pedestrians, parental factors have long been identified as an important aspect for investigation since children are normally in the care of their parents. Many studies have been conducted internationally in the area of parental factors and childhood injuries. Lawrence [23] investigated the factors that affect road risk perception among parents of children aged 4-12 years. Five factors were found to be significantly associated with parental risk perception. They included age of child, sex of parent, employment of parent, living environment, and previous injury experience. Reference [24] focused on 6 to 12 year-old children. Through an extensive survey they investigated the controlling factors of parental safety perception on children’s travel mode choice. The research showed that traffic infrastructure has a significant impact on parental decision-making concerning children’s travel mode choice.

The recent literature also emphasizes the importance of analysing the home-school paths. Even in the analysis of the risks that children encounter on home-school paths, it is crucial to focus on parents’ perceptions. Children are more likely to walk to school if their parents perceive the home-school path as a safe environment. Large and well-maintained sidewalks and safe pedestrian crossings contribute to increase parents’ safety perception [25-27].

Although a number of studies have assessed factors affecting travel mode choices for the home-school travel, little is known about Italian parents. This study therefore addresses the lack of knowledge about factors that lead Italian parents to drive their children to school rather than walking. The final aims of this study are: 1) to identify the factors affecting Italian parents' propensity to use private cars to accompany their children to school; 2) to analyse the availability of Italian parents to let their children walk to school alone.

4.3 Methods

4.3.1 Participants and questionnaire

In order to study the factors affecting parents' choice of driving their children to school instead of walking and in order to evaluate their availability to let their children walk to school on their own, an ad hoc questionnaire was developed. The survey comprised a series of questions regarding demographic features, parents' mobility habits, travel mode to school and parents' perception of road risks near the school with a focus on traffic infrastructure. The questionnaire included 21 items and it was divided into the following four sections:

- section 1 (individual demographic): the first section contained questions related to children's demographic characteristics, to parents' demographic characteristics and to the family context;
- section 2 (parents' safety perception of the home-school path): in the second section of the survey, parents were asked questions about the safety perception of the home-school path that they daily travel (driving or walking);
- section 3 (parents' choice of travel mode to school): the third section included questions related to parents' choice of travel mode to school (driving or walking) and questions related to the factors affecting such choice;
- section 4 (parents' availability to let their children walk to school): in the fourth section, parents were asked questions about the road safety measures they considered necessary in order to let their children walk the last road section to school (200 m ÷ 300 m). Parents were also asked if they would allow their children to walk to school, either on their own or accompanied.

The survey was conducted in front of 9 schools (kindergarten and primary school) in Catania, Italy. Participants were recruited in person, so as to select exclusively parents who were accompanying their children to school. Other people who were accompanying children to school (e.g. grandparents, baby sitters, etc.) were not interviewed. Participants were briefed of the nature and time required to participate in the study prior to commencement. After their consent was obtained, the questionnaire started. It was decided to question directly participants, instead of leaving them alone with the questionnaire, in order to provide visual aids and detailed explanations and clarifications. Each survey lasted approximatively 20 minutes. Participants were assured of anonymity and confidentiality.

Table 4.1 compares the sample demographic characteristics.

Table 4.1 – Features of survey respondents.

Gender	
Mother	64,30%
Father	35,69%
Child's age	
3-5	19,56%
6-8	56,14%
9-11	24,30%
Employment status	
Full-time employed	41,84%
Part-time employed	4,86%
Not employed, looking for	53,31%
Number of children to be accompanied to school	
1	68,42%
More than 1	31,58%
Travel mode to school	
Private vehicle (car/scooter)	81,40%
On foot	18,60%
Travel distance from house to school	
<500 m	23,21%
500 m ÷ 1 km	35,63%
1 km ÷ 2 km	24,97%
>2 km	16,19%
Parking availability around the school	
<100 m	15,79%
100÷300 m	6,48%
>300 m	21,19%
No availability	56,55%

The total sample comprised 1576 parents (1002 mothers and 574 fathers). Participants who didn't complete the questionnaire or who gave uncertain answers were excluded. The respondents excluded were about 6% of the sample. The final sample was composed by 1482 parents (953 mothers and 529 fathers) of children between 3 and 11 years. More than half of children was 6-8 years old, about 20% of children was 3-5 years old, and 24% was 9-11 years old. More than half of parents did not have a job. The majority of parents accompanied one child to school, while only 32% of them accompanied to school more than one child. Private vehicles (car or scooter) were the dominant mode of travel to school: about 81% of parents drove a car or rode a scooter to accompany their children to school. Very low percentage of parents walked to school with their children. The travel distance from house to school was between 500 m and 1 km for most respondents. As for parking availability, more than half of parents couldn't find parking around the school when accompanying children to school.

4.3.2 Analytical method

In order to analyse the survey data a path analysis was carried out. Path analysis is a form of Structural Equation Modelling (SEM) where all the variables are manifest variables (i.e., measureable). SEM is a series of statistical methods that enable the analysis of the relationships between a number of dependent variables (DV) and a set of independent variables (IV). Main aim of SEM is to test the validity of a certain relationship. The variables in a model can be either exogenous (not influenced by any other variable in the model) or endogenous (influenced by other variables in the model). When variables in the model are all manifest, SEM simplifies the analysis to a path analysis, in which mediation, moderation, mediated moderation or moderated mediation can all be tested [28].

Path analysis begins by assuming a specific structure, through which independent and dependent variables are related. This structure is represented by a diagram, the path diagram, and its corresponding equation system. The relations in the diagram are the parameters of the equations to be estimated, called path coefficients and are represented as pij (the influence of variable j on variable i). A conventional practice in Path analysis involves the use of standardized variables. Here, path coefficients are analogous to standardized linear regression coefficients. They represent the observed change in the dependent variable, measured in standard deviation units, relative to a one standard deviation change in the independent variable, after controlling all other independent variables with a direct effect on the dependent one. The relationship between two variables is represented by straight arrows or curves with arrows in both extremities. For an endogenous variable, the arrows represent direct causal relationship. Curves with arrows in both extremities represent a simple correlation between exogenous variables. In the model equation system, each dependent variable has a corresponding equation, in which the independent variables are represented by arrows pointing to the direction of the dependent variable. Path analysis consists, then, in estimating the coefficients of these equations (representing the amount of linear association between variables) and in using these estimates to get information on an assumed underlying causal process [29]. Although path analysis has been applied in attitude research in various fields, there are only few attempts within traffic safety [30-32].

4.3.3 Model development

Path analysis was chosen for this study since it is a technique through which multiple relationships can be tested simultaneously. The final aim was to understand how different factors affect parents' choice of driving their children to school instead of walking. In order to develop the analysis, parents' availability to allow their children to walk to school was taken into account. Therefore, the following two latent variables were considered as endogenous variables: "Driven instead of walking" and "Parents' availability". The exogenous variables were grouped into 4 categories:

- socio-demographic characteristics;
- parents' safety perception;
- reasons why parents choose to drive;
- road safety measures.

Table 4.2 shows the definition of each variable. The exogenous variables are explained in detail in the following sub-paragraphs. In order to build the path model, some hypotheses related to the relationships between the variables were made. The 6 hypotheses regarding the relationships between the endogenous and the exogenous variables are explained in the following sub-paragraphs. A further hypothesis regards the relationship between the two endogenous variables (hypothesis 7). This hypothesis was made in order to understand how many parents available to let their children walk to school choose the car instead of walking. Therefore, the variable "Parents' availability" is introduced in the model as an endogenous mediator variable. Table 4.3 summarizes the hypotheses made. Figure 4.1 shows schematically the hypothesized relationships between the variables. Figure 4.2 shows the hypothesized path model.

Table 4.2 – Endogenous variables, mediators and exogenous variables.

Variable	*Meaning*	*Values*
Driven instead of walking	Parents' choice of driving their children to school instead of walking	Never Sometimes Always
Number of children	Number of children to be accompanied to school	1 More than 1
Child's age	Age of the youngest child to be accompanied to school	3 ÷ 11
Home-school distance	Home-school distance	<500 m 500 m÷1 km 1 km÷2 km >2 km
Parking	Parking availability around the school	<100 m 100÷300 m >300 m No availability
Working parent	Working parent	Not a worker Part-time worker Full-time worker
Car-use habit	Parent's habit of using the car (for any travel)	No Yes
Excessive distance	Excessive distance home-school to walk to school	No Yes
Parent driving to work	Parent drives directly to work after accompanying the child to school	No Yes
Dangerous path	Pedestrian home-school path too dangerous	No Yes
Heavy schoolbag	Too heavy schoolbag to walk to school	No Yes
Child too young	Child too young to walk to school	No Yes
No school bus	Lack of a school bus service	No Yes
Sidewalks	Safe sidewalks (improvement or realization)	No Yes
Speed limits	Reduction of speed limits by means of signs	No Yes
Pedestrian crossings	Safe pedestrian crossing (improvement or realization)	No Yes
Traffic calming	Realization of traffic calming measures (road bumps, speed cushions, road width restrictions, chicanes)	No Yes
Crossing guards	Presence of crossing guards in front of the school	No Yes
Safety perception	Parents' safety perception of the home-school path	Low Medium High
Parents' availability	Parents' availability to let their children walk the last road section to school (200 m ÷ 300 m) if the pedestrian path was really safe	No Yes, only if accompanied Yes

Table 4.3 - Model hypotheses.

	Hypothesis
Hypothesis n.1	"Driven instead of walking" is influenced by "Socio-demographic characteristics"
Hypothesis n.2	"Parents' availability" is influenced by "Socio-demographic characteristics"
Hypothesis n.3	"Parents' safety perception" of the home-school path influences "Driven instead of walking"
Hypothesis n.4	"Parents' safety perception" of the home-school path influences "Parents' availability"
Hypothesis n.5	"Driven instead of walking" is influenced by "Reasons why parents choose to drive"
Hypothesis n.6	"Parents' availability" is influenced by "Road safety measures"
Hypothesis n.7	"Parents' availability" is a mediator variable for "Driven instead of walking"

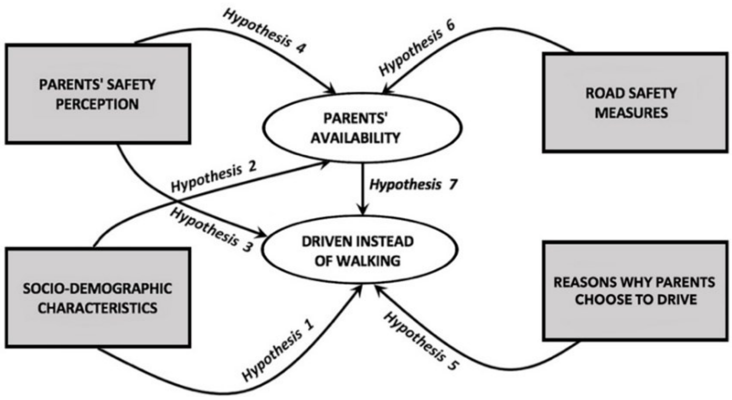

Figure 4.1 - Hypothesis scheme.

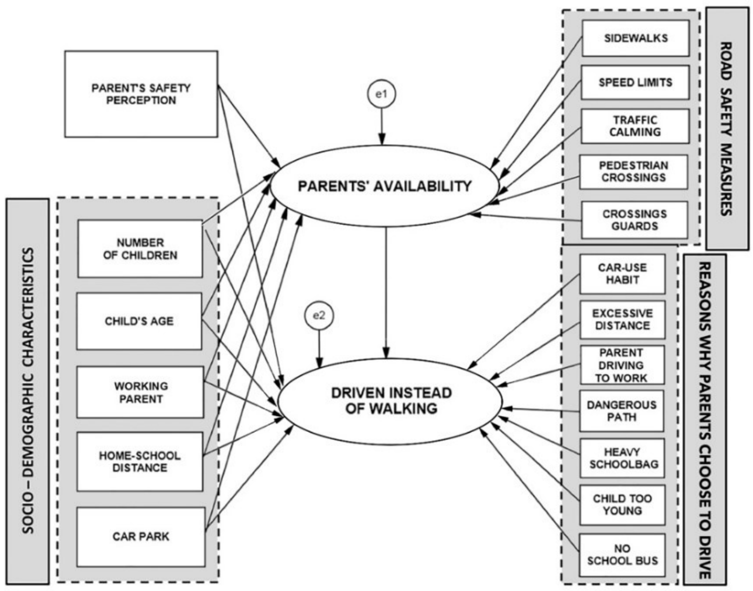

Figure 4.2 - Hypothesized path model.

4.3.3.1 Socio-demographic characteristics

Previous studies showed that children's age strongly contributes to parents' willingness to walk to school [33-35]. Reference [36] explored the association between walking to school and physical (distance from home to school and number of cars in the household) and social (working situation of parents, number of siblings) environmental characteristics in the home. Distance between home and school may influence how parents evaluate their children's ability to walk on their own, which in turn affects the decision to take (or not to take) the car [37]. Reference [38] indicated that the number of parents available to allow their children to walk to school decreased as a function of the time spent walking.

Based on the results of these studies, the "Socio-demographic characteristics" considered in this study are: "Child's age", "Number of children", "Home-school distance", "Working parent", "Parking" (Table 4.2). The variable "Parking" was introduced in order to take into account that the choice of driving instead of walking is often encouraged by the awareness of finding a regular or irregular parking space near the school. It was hypothesized that all "Socio-demographic characteristics" influence both the variable "Driven instead of walking" (hypothesis 1) and the variable "Parents' availability" (hypothesis 2).

4.3.3.2 Parents' Safety Perception

Children are more likely to walk to school if their parents have positive opinions about the safety of the home-school path [25, 27]. Parental perception of social and traffic danger is often a factor that limits the possibility of walking for children. Hillman [39] believes that, more than social fear, parental concern is the risk of road injury to their children when they are alone. Therefore, in this study it was hypothesized that the exogenous variable "Parents' safety perception" influences both the variable "Driven instead of walking" (hypothesis 3) and the variable "Parents' availability" (hypothesis 4).

4.3.3.3 Reasons why parents choose to drive

Reference [40] showed that reasons why parents choose to drive their children to school can be described as social convenience (related to parents' convenience of using the car) and safety (related to parents' concerns about their children encountering difficulties on their way to school). The results further showed that distance does not strongly affect the decision to drive since lots of parents choose to drive even for a short distance. Reference [41] introduced the weight of schoolbags as a relatively new factor among the reasons why parents choose to drive.

Based on the results of these studies and considering the reasons parents stated during the survey we developed, the “Reasons why parents choose to drive” considered in this study are: “Car use habit”, “Excessive distance”, “Parent driving to work”, “Dangerous path”, “Heavy schoolbag”, “Child too young” and “No school bus” (Table 4.2). It was hypothesized that all these variables influence only the variable “Driven instead of walking” (hypothesis 5).

4.3.3.4 Road Safety Measures

Traffic safety has a significant impact on parental decision-making concerning children’s travel mode choice [24,42]. Reference [21] showed that traffic calming measures are strongly, significantly, and positively correlated with the percentage of students walking or cycling to school. Previous parent surveys revealed that parents are most likely to feel concern about streets that lack sidewalks or have sidewalks with obstructions [43], that the speed of cars is their highest concern [10] and that traffic controls do not modify their concern [43]. Walking to school is more frequent among children attending schools in neighbourhoods of low traffic volume [44]. Reference [45] showed that the number of crossings, the width of the road and the presence of crosswalks are significantly and positively associated with perceived crash risk among school-aged children.

The “Road safety measures” considered in this study result directly from what parents declared during the survey. The road safety measures that parents declared would like to be realized or improved on the home-school path in order to let their children walk to school were therefore considered as variables for this study. These variables are: “Sidewalk”, “Speed limits”, “Traffic reduction”, “Pedestrian crossings”, “Crossing guards” (Table 4.2). It was hypothesized that the variables of this category affect only the variable “Parents’ availability” (hypothesis 6).

4.4 Results and Discussion

Path analysis enables to estimate all the model parameters at the same time. This is a very efficient method of estimation and provides reliable estimates. Path estimates can be interpreted as regression coefficients and moderation effects. In this study, they were estimated using AMOS 24.0.

Table 4.4 shows the mean scores of the path analysis: unstandardized coefficients estimates with relative standard errors, standardized coefficients and p-value. Unstandardized coefficients estimates retain scaling information of variables involved and can only be interpreted with reference to the scales of the variables. Standardized coefficients estimates are transformations of unstandardized estimates that remove scaling information and can be used for informal comparisons of parameters throughout the model. Standardized estimates correspond to effect size estimates.

Table 4.4 - Modelling results.

	Variable	*Estimate*	*Standard Errors*	*Standardized coefficients*	*p-value**
Driven instead of walking	Car-use habit	0.331	0.031	0.199	< 0,001
	Excessive distance	0.067	0.031	0.041	0.029
	Parent driving to work	0.142	0.030	0.090	< 0,001
	Dangerous path	0.016	0.039	0.008	0.688
	Heavy schoolbag	0.002	0.034	0.001	0.944
	Child too young	0.154	0.044	0.066	< 0,001
	No school bus	-0.001	0.033	-0.001	0.972
	Number of children	0.139	0.026	0.123	< 0,001
	Child's Age	0.027	0.007	0.075	< 0,001
	Working parent	0.124	0.014	0.169	< 0,001
	Home-school distance	0.343	0.014	0.485	< 0,001
	Parking	0.232	0.012	0.361	< 0,001
	Safety perception	-0.018	0.018	-0.019	0.321
	Parents' availability	-0.059	0.022	-0.055	0.006
Parents' availability	Number of children	0.131	0.030	0.105	< 0,001
	Child's Age	0.086	0.008	0.254	< 0,001
	Working Parent	0.077	0.016	0.112	< 0,001
	Home-school distance	-0.107	0.016	-0.168	< 0,001
	Parking	0.016	0.014	0.027	0.260
	Safety perception	0.027	0.021	0.030	0.210
	Sidewalks	0.041	0.032	0.030	0.208
	Speed limits	-0.039	0.032	-0.029	0.223
	Pedestrian crossings	0.076	0.032	0.067	0.017
	Traffic calming	0.202	0.032	0.141	< 0,001
	Crossing guards	0.064	0.033	0.047	0.049

Note: 95% confidence level in used (i.e., p-value<0.05 is statistically significant).

The results of the path analysis are shown as a pyramid diagram [46]. The pyramid diagram has a hierarchical structure and it is subdivided into a number of sections equal to the variables that have statistically significant effects on the endogenous variables (p-value < 0.05). At the top of the pyramid there are the exogenous variables characterized by standardized coefficients closest to the perfect relationship, positive or negative, with the endogenous variables. Each section can be identified by the sign "+" or "-" and relates to the exogenous variable that has a significant association with the endogenous variable, positively or negatively.

The variables related to each section are sorted in descending order on the basis of the absolute value of the standardized coefficients; such sorting gives rise to the ordered sequence of the signs attributed to the single sections constituting the pyramid structure. Thanks to the pyramid diagram, it is possible to visualize clearly the existing relationships between the endogenous and the exogenous variables.

In Figure 4.3 the values on the arrows are the standardized coefficients estimates between the variables. These values represent the standardized relationships between the variables and can range between -1.0 (perfect negative relationship) and 1.0 (perfect positive relationship), with 0.0 meaning no relationship. Thus, if variable X has a 0.50 effect on variable Y, it means that for every standard deviation increasing X, Y will increase by 0.50 standard deviations. Indirect effects are interpreted by multiplying coefficients along a path.

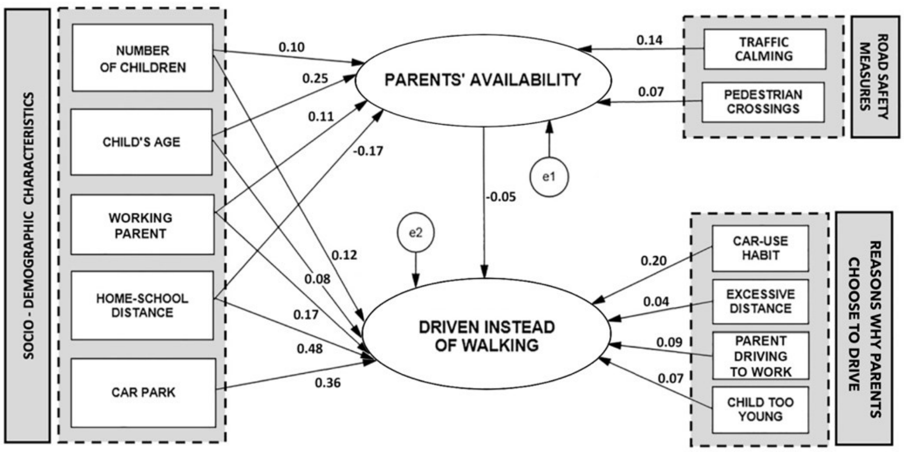

Figure 4.3 - Hypothesized Final Path Diagram.

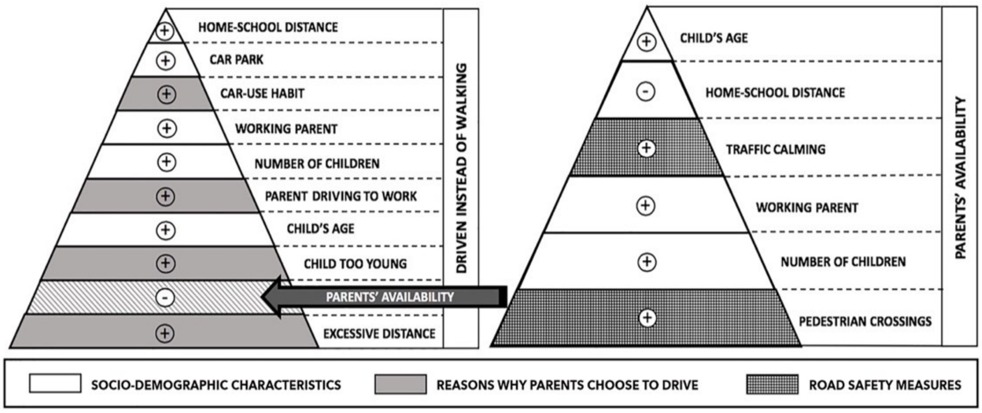

Figure 4.4 - Pyramid Diagram.

4.4.1 Parents' Availability

The analysis of Table 4.4 leads to the conclusion that four out of five variables belonging to the category of "Socio-demographic characteristics" are statistically significant (p-value < 0,05) for the mediator variable "Parents' availability". Hypothesis 2 is therefore partially verified. The variables mostly influencing "Parents' availability" are "Child's age" and "Home-school distance". They are indeed at the top of the pyramid diagram related to "Parents' availability" (Figure 4.4).

The maximum positive correlation of the variable "Child's age" shows that the older children are, the more parents are predisposed to let their children walk to school alone, even if for the last part of the travel (a few hundred meters). The negative correlation of the variable "Home-school distance" shows that the excessive home-school distance encourages parents to drive their children to school. The other two variables belonging to the category of "Socio-demographic characteristics", i.e. "Working parent" and "Number of children", have a positive correlation with "Parents' availability". It is not surprising that the variable "Working parent" has the same sign and it is in a similar position both in the pyramid diagram related to "Parents' availability" and in the pyramid diagram related to "Driven instead of walking". In the pyramid diagram related to "Driven instead of walking" the positive correlation of the variable "Working parent" can be explained considering that the condition of working parent encourages the use of the car. On the other hand, in the pyramid diagram related to "Parents' availability" the positive correlation of the variable "Working parent" can be explained considering that the social level of parents who have a stable job affects positively their predisposition to let their children walk the last part of the home-school path.

Hypothesis 4 (i.e. “Parents’ safety perception” of the home-school path influences “Parents’ availability”) is not confirmed. The variable “Parents’ safety perception” is indeed statistically not significant (p-value of 0,210) and it is not therefore represented in the pyramid diagram.

As for the variables belonging to the category “Road safety measures”, only “Traffic calming” and “Pedestrian crossings” are statistically significant. Hypothesis 5 is thus partially verified. The variable of this category most influencing “Parents’ availability” is “Traffic calming”, which is in the upper section of the central area of the pyramid diagram. Aggressive driving behaviours towards pedestrians and parking manoeuvres near the school are indeed factors that lead parents to consider traffic reduction as a priority. The variable “Pedestrian crossings” is at the base of the pyramid diagram, even though has a positive correlation with “Parents’ availability”.

4.4.2 Driven Instead of Walking

From Table 4.4 it can be seen that only four out of seven variables of the category “Reasons why parents choose to drive” are statistically significant (p-value < 0,05) for the variable “Driven instead of walking”. Hypothesis 5 is therefore partially verified. The pyramid diagram related to the variable “Driven instead of walking” (Figure 4.4) shows that the variable mostly influencing “Driven instead of walking” is “Car-use habit”. It is indeed in the upper section of the pyramid diagram related to “Driven instead of walking” (Figure 4.4). This is a confirmation of the established Italians’ habit of using a private vehicle, excluding a priori other means of transport. The variable “Parent driving to work” also has a quite important positive correlation with the endogenous variable “Driven instead of walking” (in fact it is in the central part of the pyramid diagram). Family organization plays indeed an important role in choosing a private vehicle because the working parent plans the home-school-work itinerary compatibly with their children’s school and their work starting times. The variables “Child too young” and “Excessive distance” are at the base of the pyramid and they therefore contribute less in encouraging parents to use a private vehicle.

All the variables belonging to the category “Socio-demographic characteristics” are correlated positively to “Driven instead of walking”. Hypothesis 1 is therefore verified. Parents’ choice of a means of transport is mostly influenced by the two variables “Home-school distance” and “Parking”. They are indeed at the top of the pyramid diagram related to “Driven instead of walking”. This means that excessive length of home-school paths discourages parents from walking. Moreover, parents’ awareness of finding parking spaces near the school encourages the use of the car. The variables “Working parent” and “Number of children” are at the centre of the pyramid and also have a positive correlation with “Driven instead of walking”. The variable “Child's age” is close to the base of the pyramid diagram, even though it has a positive correlation with “Driven instead of walking”, and therefore it does not seem to have a strong influence on parents' choice of driving.

It is interesting to note that both the variables associated to children’s age (i.e. “Child too young” and “Child's age”) are at the bottom of the pyramid diagram related to the endogenous variable “Driven instead of walking”. However, it is believed that this is not representative of the low influence of these variables on the endogenous variable. Rather, the context of analysis limited exclusively to young children (from 3 to 10 years old) probably overshadows the influence of children’s age on parents’ choices. Respondents are indeed parents of children attending kindergarten and/or primary school. That is precisely why the importance of children’s age does not arise clearly neither from the questions related to “Reasons why parents choose to drive”, nor from the analysis of the variables related to “Socio-demographic characteristics”.

It is also interesting to note that the variable “Home-school distance” is at the top of the pyramid diagram while the variable “Excessive distance” is at the base. This apparent contradiction can be explained considering that some parents live near the school, others live far away. The variable “Home-school distance” is objective and independent from the respondents’ statements and it therefore attests the strong influence of the home-school distance on the choice of driving. The variable “Excessive distance” is the result of parents deliberately saying that the excessive distance home-school is one of the reasons why they choose to drive. This is why it has a weak influence on the choice of the means of transport.

Hypothesis 3 (i.e. “Parents’ safety perception” of the home-school path influences “Driven instead of walking”) was not verified. The variable “Parents’ safety perception” is indeed statistically not significant (p-value of 0,321) and it is therefore not represented in the pyramid diagram. Parents’ preference for the car is indeed not affected by their perception of the home-school path as totally unsafe. It is interesting that both the variable “Dangerous path” (belonging to the category “Reasons why parents choose to drive”) and the variable “Parents’ safety perception” are statistically not significant although they were deduced from different sections of the questionnaire. The dangerousness of the home-school path does not affect the choice of the means of transport.

Finally, the results show that there is a negative correlation between the mediator variable “Parents' availability” and the endogenous variable “Driven instead of walking” (hypothesis 7); this means that parents who are more available to let their children walk to school are mentally predisposed to drive less. The low absolute value of the standardized coefficient associated to the correlation between “Parents' availability” and “Driven instead of walking” suggests that other variables affect more parents’ preference for the car. However, the combined analysis of the path diagram and of the pyramid diagram shows that the realization of measures favouring “Parents' availability” is essential in order to mitigate the preference for the private vehicle, still deeply rooted in Italy. It is believed that by encouraging “Parents' availability” in the near future it could be obtained a new pyramid diagram related to the endogenous variable “Driven instead of walking” where “Car-use habit” gets closer to the base and, vice versa, “Parents' availability” gets closer to the top of the pyramid.

4.5 Conclusions

This paper final aim was to investigate the reasons that lead Italian parents to drive their children to school rather than walking. Furthermore, parents' availability to let their children walk to school alone has been tested. The results show that in Italy the habit of driving children to school is still very common. Main reasons why parents drive their children to school are the lack of safe home-school paths and the availability of regular or irregular parking spaces near the school. These results can be useful for those involved in transport planning and safety in order to implement effective actions aimed at encouraging the use of one or several human-powered modes of transportation such as walking or cycling. Several recent studies demonstrated the effectiveness of information and sensitization strategies, such as “Safe Routes To School” (SRTS) programs in the US. References [47,48] evaluated the impact of “Safe Routes To School” using large samples of schools and SRTS projects, and reported a significant increase in the rate of students walking or cycling to school among those that participated in SRTS programs.

In Italy, little has been done in order to discourage the use of private vehicles and encourage walking and cycling to school. The results of this study could be very helpful for developing guidelines on implementation of policies to improve the safety of home-school paths. This research confirms the importance of information and sensitization strategies, which should be implemented involving both children and their parents. The results furthermore suggest that infrastructure-centred interventions, such as traffic calming measures and safer pedestrian crossings, can increase parents' safety perception of the home-school paths and thus raise the probability that children walk to school. It is in everyone's interest that traffic environments are suitable for children from both safety and functional points of view. If an appropriate protection of children were guaranteed, parents would be encouraged to let them walk to school, which would turn into decreasing risk of car dependence for future adults. Moreover, there would be the collateral benefit of getting children used to the traffic environments from an early age, which would lead them to develop a great civic sense and to evolve into appropriate road users when adults.

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5. DRIVER ELECTRODERMAL ACTIVITY AND SPEED VARIATION ASSOCIATED TO DIFFERENT ROAD INTERSECTIONS

This chapter intends to contribute for a better understanding of drivers' physiological and behavioural responses when approaching T-junctions and roundabouts. The ultimate aim is to understand how at grade intersections affect the driving behaviour by comparing speed and electrodermal activity variations induced by roundabouts with T-junctions. Speed and electrodermal activity were therefore collected continuously during a driving study which took place on a test environment based at Cranfield University and surrounding roads. Two different approaches were used in order to investigate the relationship between different types of intersections and the human factor. The first approach focuses on the analysis of electrodermal activity. The second approach uses the association Rule with the Apriori algorithm in order to evaluate associations between electrodermal activity and speed. The two approaches gave rise to two studies, which are reported in this chapter respectively in paragraph 5a and paragraph 5b and were published or submitted for publications to:

- *Distefano, N., Leonardi, S., Pulvirenti, G., Romano, R., Merat, N., Boer, E., Woolridge, E., 2019. Physiological and driving behaviour changes associated to different road intersections. Transportation Research Procedia. AIIT 2nd International Congress on Transport Infrastructure and Systems in a changing world. (TIS ROMA 2019), 23rd-24th September 2019, Rome, Italy.*
- *Distefano, N., Leonardi, S., Pulvirenti, G., Romano, R., Boer, E., Woolridge, E. Mining of the association rules between driver electrodermal activity and speed variation in different road intersections. Submitted for publication to Accident Analysis and Prevention.*

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Transport Systems Catapult. Cranfield University performed the data collection for the experiment. Innovate UK do not approve the technical content of academic papers. The work was also partially financed by the University of Catania within the project “Piano della Ricerca Dipartimentale 2016-2018” of the Department of Civil Engineering and Architecture.

5a Physiological and driving behaviour changes associated to different road intersections

5a.1 Introduction and background

Hazard perception, i.e. the ability to “read the road” in relation to potentially dangerous situations in the traffic environment, seems to be the only component of driving skills that has been found to be related to accident involvement (Horswill and McKenna, 2004). For many decades road safety researchers have been attempting to explain how people perceive and understand risk (McKenna and Crick, 1997; Borowsky et al., 2010). The reason that hazard-perception ability has retained interest over the years is because anticipation of hazardous traffic situations is perhaps one of the major contributions to driver safety. It is commonly acknowledged that human factors may contribute to accident involvement in traffic (Grayson and Maycock, 1988). Based on a study of 2041 traffic accidents, Sabey and Taylor (1980) concluded that human factors were contributing elements in 95% of the accidents. Driving behaviour was identified as the most central of these factors. Driving attitude, which is manifested by driving behaviour, strongly affect the hazard perception of drivers (Cheng et al., 2011). It is therefore important to understand the various aspects that affect the drivers’ ability to perceive danger and risk and, thus, that affect their driving behaviour. Human driving behaviour, and so hazard perception ability, is strongly conditioned by the road environment in its entirety, as driving involves complex interactions between the driver and the environment. Considering the extreme complexity of road networks, the aspects influencing the driving behaviour should be studied with specific regard to the elements of road networks as, for example, intersections. The meeting point of two or more roads is the focus of conflict since the beginnings of regular traffic. Intersections are among the most complex road environments: their geometric configuration, the signs and markings, the road furniture, the qualitative and quantitative characteristics of traffic, the vehicular conflicts are all elements which weigh the driver workload, conditioning the driving behaviour and, consequently, affecting the risk of accident. The safety benefit of roundabout conversions has been recognized world-wide. Several studies to date have examined the safety implications of replacing standard intersections with roundabouts. Converting junctions to roundabouts has been found to reduce the number of accidents, in particular fatal accidents (Elvik, 2003; Persaud et al., 2001; Vujanić, 2016). Studies of roundabouts in various countries have shown that roundabouts can significantly improve functional characteristics (Easa and Mehmood, 2006; Ma et al., 2013), as well as traffic safety (Chen et al., 2013; Gross et al., 2013). Lot of researchers also examined the relationship between geometric elements and safety benefits in roundabouts (e.g. Daniels et al., 2010, Distefano et al., 2018). While previous studies investigated the benefits of converting junctions into roundabouts as for crash rates and traffic conditions, to the best of the authors' knowledge, no studies analysed how drivers' stress level change between standard intersections and roundabouts. Research on user behaviour and perceptions can be a helpful tool in improving road safety and accident prevention. The aim of this study is to evaluate drivers' physiological and behavioural responses in order to assess drivers' risk perception for standard intersections and roundabouts and compare them. The authors indeed believe that there is a need to deepen the human interactions with the road environment for different intersections. This paper presents a method for measuring and quantifying drivers' overall stress in a real environment using physiological signals. Physiological signals are a useful metric for providing feedback about a driver's state because they can be collected continuously and without interfering with the driver's task performance and with the drivers' perception of the road. When humans are subjected to stressors, they tend to show a variety of physiological responses such as pupil dilation, increased heart rate, slowed digestion, and a constriction of blood vessels, mechanisms that are collectively known as the 'fight-or-flight' response (Cain, 2007; Wickens et al., 2004). Measuring drivers' physiological responses during periods of effort investment in simulators and real vehicles has been a subject of investigations for several decades. Examples include physiological measurements during the presence/absence of a secondary task (Mehler et al., 2009), as a function of road infrastructure (Dijksterhuis et al., 2011), or for different levels of automated driving (De Winter et al., 2014). The Autonomic Nervous System (ANS), responsible for involuntary activities, is made up of Sympathetic and Parasympathetic nervous systems. Stressful events or emergency situations cause dynamic changes in ANS, where the activity rate in the Sympathetic Nervous System (SNS) increases and the Parasympathetic Nervous System (PNS) activity decreases. Alternatively, activities in the PNS dominate during resting activities. SNS and PNS regulate the electrodermal activity, heart rate variability, and brain waves, which are the main measures for stress used in literature, and other physiological systems including blood pressure. Electrodermal activity, also known as galvanic skin response or skin conductance, is a reliable indicator of stress (Seyle, 1956). Electrodermal activity (EDA) refers to the variation of the electrical properties of the skin in response to sweat secretion. The whole mechanism is controlled by the sympathetic nervous system and can be used to control the functionality of the cognitive system. By applying a low constant voltage, the change in skin conductance (SC) can be measured non-invasively (Fowles et al.,1981). The time series of SC can be categorized into two components: tonic (i.e., skin conductance level; SCL) and phasic components (i.e., skin conductance response SCR) that have different time scales and relationships to external stimuli (Cacioppo et al., 2007). Specifically, SCR is a useful index of an individual's perceived risk. SCR could be a useful indicative of activities of the sympathetic branch of the autonomic nervous system because the sweat glands are innervated by the sympathetic nervous activities (Poh et al., 2010). The sympathetic arousal stimulated by external stressors could be reflected by a higher SCR. In this sense, EDA has been used to understand an individual's mental status related to sympathetic arousal (e.g., stress, attention, risk perception, etc.) in various situations such as occupational setting, human-computer interaction, traffic and automation, and marketing and product evaluation (Boucsein, 2012). SCR could be a more useful index of the perceived risk than other physiological signals such as heart rate, respiration rate, and skin temperature because SCR is the only autonomic physiological variable that is not contaminated by the parasympathetic branch of the autonomic nervous system (Braithwaite et al., 2013).

5a.2 Method

5a.2.1 Participants

Twenty-three staff members were recruited from Cranfield University, three individuals participated within pilot trials and twenty individuals participated within the trials. An advert was placed on the Cranfield University website, and participants who showed interest were sent an email which included information about the study and a participant recruitment questionnaire. The questionnaire data was used to determine the appropriate participant sample and participants were invited to participate within the study. The twenty participants involved within the trial were evenly divided between males and females. Participants were aged twenty-eight to fifty years of age. They were required to have held a UK driving licence for a minimum of three years. One participant was excluded from the analysis because of a problem during the data collection. The final sample therefore consisted of nineteen participants (ten males and nine females). An ethics application was made for the experiment to the Research Ethics committee at Cranfield University and received approval. Participants gave their informed consent to take part in the experiment. They were informed that all information collected would have been dealt with in the strictest confidence and would have only been used for research purposed. Participants were also informed that they would have not been judged as for their ability as drivers and that the only aim of the study was to analyse the behaviour of a group of drivers to draw conclusions about drivers in general.

5a.2.2 Experiment design

The trial was a naturalistic user study which aimed to explore and capture the user's natural behaviours in the real-world. The experiment was part of the "HumanDrive" project. The "HumanDrive" project goal is to develop driverless vehicle technologies that can deal with varied UK driving scenarios in a more humanlike way. The ego vehicle driven by the participant was a Nissan Leaf. The vehicle was instrumented with an OXTS RT1003 vehicle localisation system (which allowed to record vehicle position, forward speed, linear acceleration and GPS time at 100 Hz) and three colour cameras (one forward facing, one driver facing, one steering wheel facing). An Empatica E4 wrist band sensor was worn by the participant to collect physiological data which records their blood pulse volume and their skin conductance. The study involved time for the participants to familiarise themselves with the vehicle, participant 'within trial' data collection, followed by interviews to further understand their driver behaviour. Before the drive could be carried out the participant had to be familiar with the vehicle and how to control it. The ego vehicle dimensions, operation and electric drive train may be new to the participant. Therefore, a tutorial was provided to explain how the vehicle works, whilst the vehicle was stationary. Moreover, a familiarisation period was built into the study to ensure that participants had adequate time to get familiar with the vehicle and a similar level of familiarisation was achieved across all participants to prevent experimental bias. The familiarisation drive was accompanied by a facilitator, sitting in the back of the vehicle behind the driving seat and issuing directions. The facilitator had to confirm during and/or at the end of the familiarisation drive that the participant was confident driving. After this phase the driving study started. Participants were asked to drive naturally. As well as the familiarisation drive, directions were issued by the facilitator who was sat directly behind the driver's seat. Trials took place between 9am and 4pm, to ensure similar and bright visibility and avoid busy commuter traffic. When experience adverse weather such as heavy rain or snow were experienced, the trial was postponed.

5a.2.3 Study location

The driving study took place on the MUEAVI (Multi-User Environment for Autonomous Vehicle Innovation) test environment based at Cranfield University and surrounding roads. MUEAVI is a controlled and instrumented stretch of road, located on the edge of the University Campus. Both public roads and campus roads link to the MUEAVI facility, these roads were also incorporated within the trial, particularly to further assess interactions with the roundabouts and intersections. Figure 5a.1 shows the study location and the driving route. It can be seen the driving route composed by the loop around Cranfield and the MUEAVI (central quadrant) and the familiarisation drive (upper left quadrant). Participants drove the route different times continuously and therefore they made different manoeuvres on the different intersections situated on the driving route. The present study focuses on the drivers' risk perception of three intersections situated on the study location. These intersections are the roundabout R and the two T-junctions T1 and T2 shown in Figure . The roundabout has three perpendicular legs and a diameter of 45 meters approximately. The T-junctions have the three legs perpendicular to each other and have similar dimensions. The analysis made regards the drivers' stress level during a crossing manoeuvre for each T-junction (manoeuvre 1 and manoeuvre 2) and during two crossings manoeuvres on the roundabout (manoeuvre 3 and manoeuvre 4). We chose to compare crossing manoeuvres, rather than turning right or turning left manoeuvres, because the speed for crossing manoeuvres is higher than for other manoeuvres. Since the final aim of the study was to evaluate how the type of intersection affects drivers' risk perception, we analysed only the manoeuvres where the traffic was not affecting the driving behaviour (no traffic or really low traffic at the intersection during the execution of the manoeuvres).

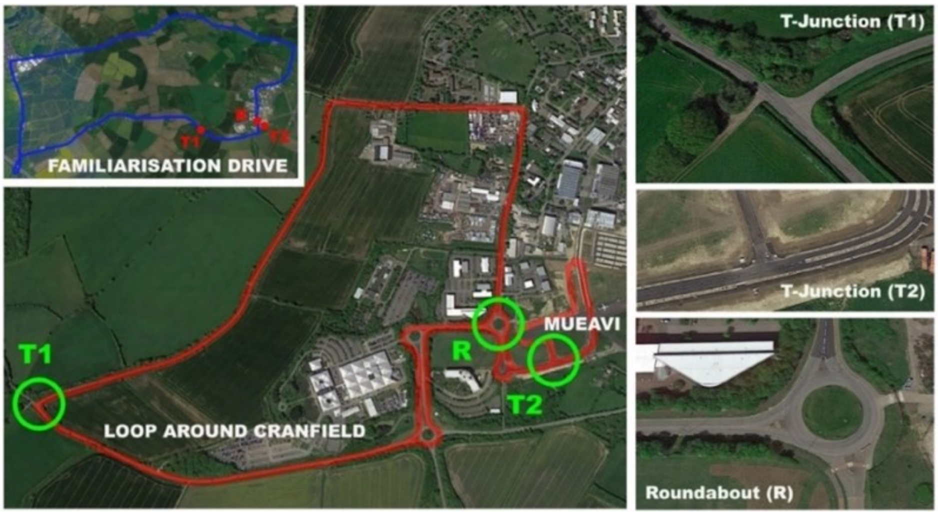


Figure 5a.1 - Study location.

5a.2.4 EDA recording

Recent advancements in wearable technologies allowed to overcome the limitations of traditional EDA sensors. Wearable sensors (e.g., off-the-shelf wristband-type wearable sensor) can continuously collect drivers' physiological signals without affecting driving conditions. Empatica E4 wristband (Empatica Inc., Cambridge, MA, USA) was used to record EDA continuously and unobtrusively during the experiment. Participants wore the wristband on their right wrist. In contrast to lower-accuracy, consumer-oriented wristband sensors available on the market - typically for fitness tracking - the E4 is a research quality multi-sensor wristband (Garbarino et al., 2014). The wristband embeds four sensors: EDA, photo-plethysmograph, thermometer, and accelerometer. The E4 wristband EDA sensor uses the exosomatic method, which measures skin conductance in microSiemens (μS) by applying a small external current. The sampling frequency of the EDA sensor is 4 Hz (i.e., four samples per second).

5a.2.5 Data analysis

As aforementioned, EDA can be decomposed by a slowly varying tonic activity (i.e., skin conductance level; SCL) and a fast-varying phasic activity (i.e., skin conductance response SCRs). The tonic level, known as skin conductance level (SCL), slowly varies and changes slightly on a time scale of tens of seconds to minutes. The rising and declining SCL is constantly changing within an individual respondent, depending on their hydration, skin dryness, or autonomic regulation. The tonic level can also differ markedly across individuals. This has led some researchers to conclude that the actual tonic level on its own is not that informative (Braithwaite et al., 2013). The phasic response rides on top of the tonic changes and shows significantly faster alterations. Variations in the phasic component are visible as EDA peaks. The phasic response is also labelled skin conductance response (SCR) as it is sensitive to specific emotionally arousing stimulus events (event-related SCRs, ER-SCRs). These bursts occur between 1-5 seconds after the onset of emotional stimuli. By contrast, non-specific skin conductance responses (NS-SCRs) happen spontaneously in the body at a rate of 1-3 per minute and are not a consequence of any eliciting stimulus. SCRs may reflect stimulus-specific responses or non-specific responses. An SCR shows a steep incline to the peak and a slow decline to the baseline. The succession of SCRs usually results in a superposition of subsequent SCRs, as more often than not, a subsequent SCR occurs during the decay of a previous one. Hence SC does not show distinct peaks of phasic activity, but rather is characterized by the superposition of extended responses, which eventually complicates the assessment of responses (Boucsein, 2012). Continuous decomposition analysis (Benedek and Kaernbach, 2010) was used in this study for extracting SCRs peaks, as it enables separate detection of superimposed responses. The data were therefore analysed by determining the number of peaks in the skin conductance response (SCR) that subjects had while driving on each intersection through the following procedure. The phasic data (SCR) was extracted from the EDA signal by using a median filter. For each sample, the median EDA score of the surrounding samples was calculated based on a +/- 4 seconds interval centred on the current sample. This value was then subtracted from the current sample to obtain the phasic data. Peaks onset/offset thresholds were set to 0.01 μS and 0 μS respectively (Benedek and Kaernbach, 2010). Peak onset value represents the starting point in time where a peak is detected, while the offset value represents the time when a peak has passed. To avoid false positives, the onset value was not counted if it is less than 0.01 μS. The maximum original EDA data within each pair of onsets and offsets is an SCR peak. SCR peak amplitude is the amplitude at the peak divided the amplitude at onset. A peak was only considered if its amplitude was higher than the threshold amplitude by 0.005 above the onset value. Also, a signal jump threshold that accounts for false peaks - caused by noise - is set to 0.02 μS. After continuous decomposition analysis, onsets for each individual SCR were obtained. Onsets served as the basis to subsequently calculate the number of SCR peaks and their amplitude, using a moving window approach with a temporal window corresponding to 100 m before and 100 m after each intersection. QGIS 3.6 was used in order to identify the temporal window corresponding to 100 m before and 100 m after each intersection starting from the GPS traces.

5a.3 Results

Figure shows the number of SCR peaks (Figure -a) as well as the average amplitude of peaks (Figure -b) of all subjects during each crossing manoeuvre on the two T-junctions (manoeuvres 1 and 2) and during each crossing manoeuvre on the roundabout (manoeuvres 3 and 4). For statistical analysis, initially descriptive statistics were calculated for the SCR through SPSS 24.0. For further SCR data treatment, Levene's test was performed. The Levene's test results for SCR measurements in terms of average peaks amplitude for the two groups (T-junctions and roundabouts) were: Levene statistic = 1.675; df1 = 1.00; df2 = 85; corresponding p value = 0.199 (> 0.05). According to the Levene's test, variances are equal for the two groups and the criterion of homogeneity is met. We proceeded with Kolmogorov–Smirnov testing for the normality of each group of data and the results showed that both data series were not parametric. For the purposes of comparison between groups, we used a Kruskal–Wallis test for the two groups and measured their SCR (peaks amplitude). The Kruskal–Wallis test results indicate that there is a statistical difference between groups with p value = 0.047 (< 0.05). For further investigation we used a Mann-Whitney test. A statistical difference was found between the two groups (Mann-Whitney U = 620.00; Wilcoxon W = 1055.00; Z = -1.990; corresponding p value = 0.047 < 0.05). Finally, the Two-Sample Kolmogorov-Smirnov Test showed a statistical difference between the two data series (Most Extreme Differences: Absolute = 0.328, Positive = 0.034, Negative = -0.328; Kolmogorov-Smirnov Z = 1.440; corresponding p value = 0.032 < 0.05). In order to evaluate the overall influence of roundabouts and T-junctions on drivers' risk perception, the total number of SCR peaks and the average amplitude of SCR peaks for the manoeuvres on the T-junctions and for the manoeuvres on the roundabout were calculated for each participant (Figure -a and Figure -b). From the analysis of Figure and Figure it can be seen that thirteen out of nineteen participants had more SCR peaks during the manoeuvres on the roundabout rather than during the manoeuvres on the T-junctions; ten of them also had a higher amplitude of the peaks during the manoeuvres on the roundabout. Eleven out of nineteen participants show a higher amplitude of the SCR peaks during the manoeuvres on the roundabout. Four participants had the same number of peaks during the manoeuvres on the roundabout and during the manoeuvres on the T-junctions. One participant (participant 5) did not show any peak at all. Only one participant had more SCR peaks during the manoeuvres on the T-junctions rather than during the manoeuvres on the roundabout (participant 11). The number of SCR peaks as well as the amplitude of the peaks are overall higher for the manoeuvres on the roundabout (number of peaks: 58 for roundabout, 29 for T-junctions; medium amplitude of peaks: 1.132 for the manoeuvres on the roundabout, 1.083 for the manoeuvres on the T-junctions. These results can be interpreted for increased anxiousness (higher emotional response) with respect to baseline (Villarejo et al. 2012), with more impact in the roundabouts.

In order to further assess drivers' risk perception for T-junctions and roundabouts and to evaluate the stress level induced by each type of intersection, an index representing the driver's stress level at each type of intersection was defined. This index, named Electrodermal Impact Index, was calculated as the product of the number of SCR peaks and the average amplitude of SCR peaks (Table 5a.1). We obtained an Electrodermal Impact Index of 65.66 for the crossing manoeuvres on the roundabout and an Electrodermal Impact Index of 31.41 for the crossing manoeuvres on the T-junctions. The ratio between these two Electrodermal Impact Index shows that roundabouts are affecting the drivers' stress level and so the drivers' risk perception 2.1 times more than T-junctions.

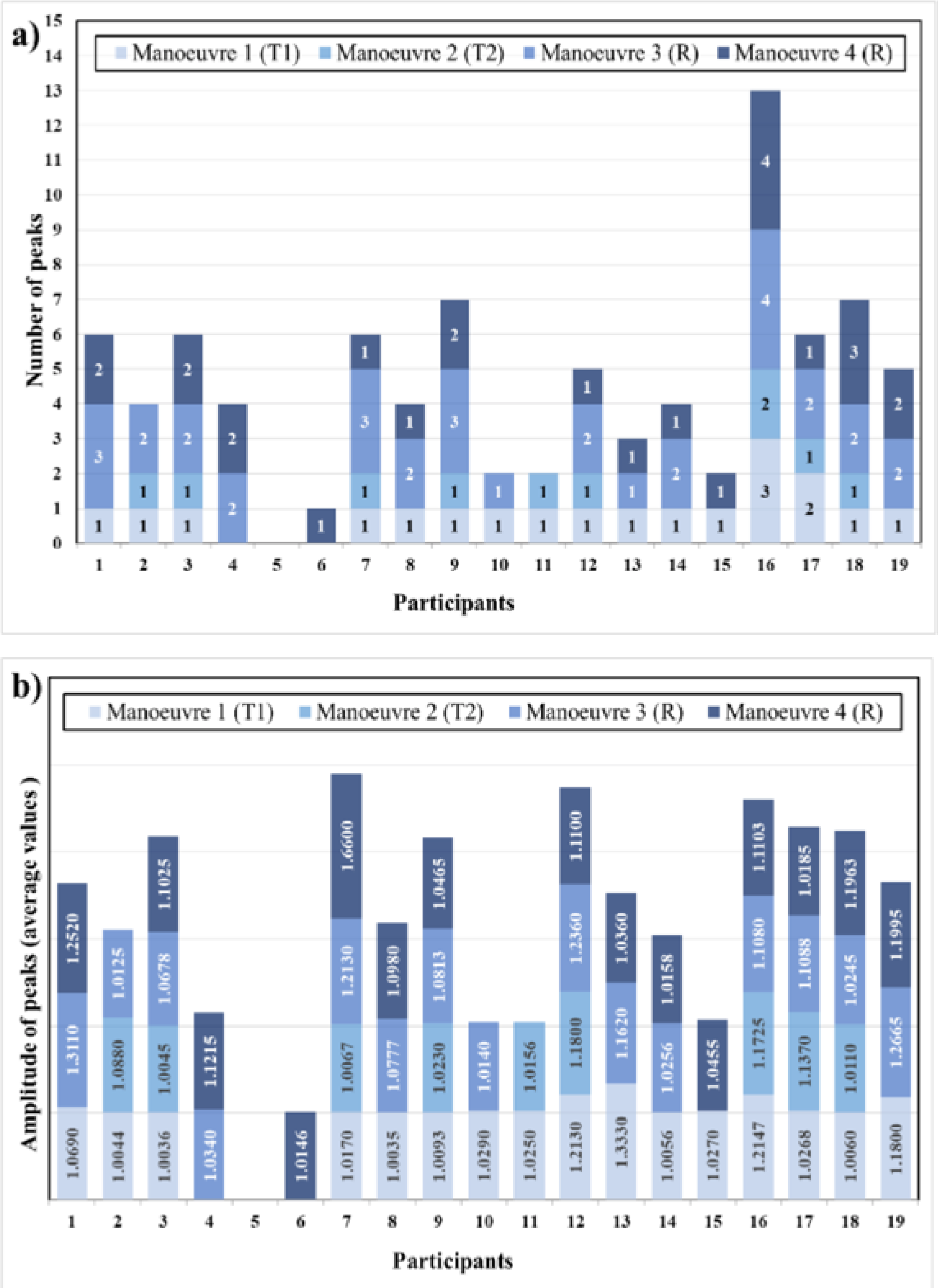
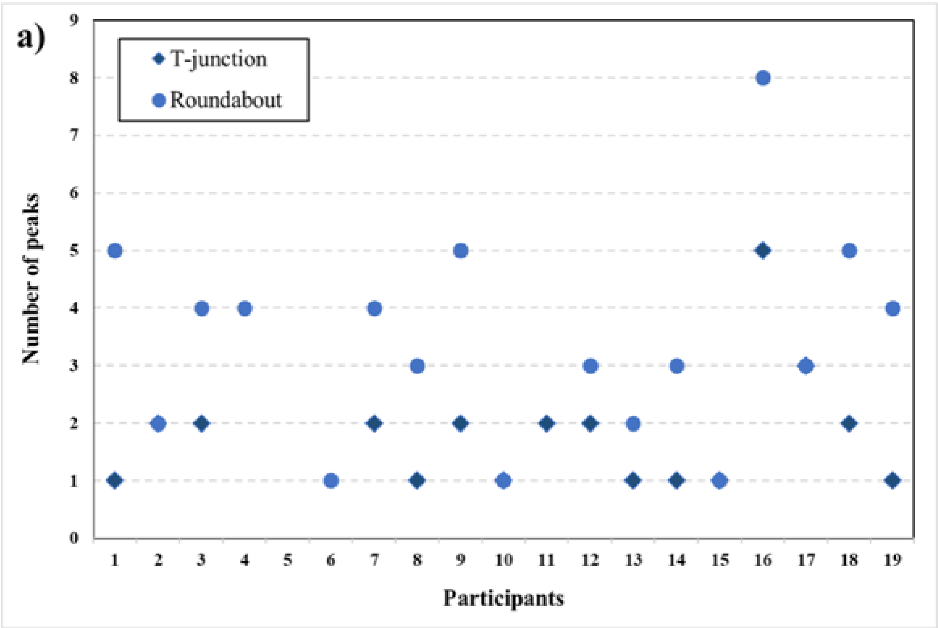


Figure 5a.2 - (a) Number of SCR peaks of all subjects during each crossing manoeuvre on the two T-junctions (T1 and T2) and during each crossing manoeuvre on the roundabout (R); (b) average amplitude of SCR peaks of all subjects during each crossing manoeuvre on the two T-junctions (T1 and T2) and during each crossing manoeuvre on the roundabout (R).



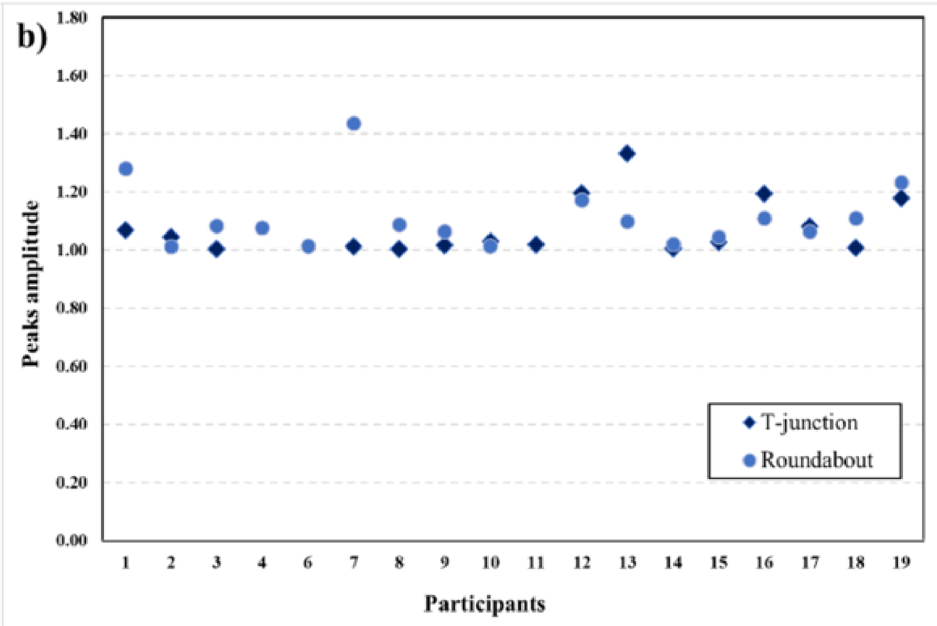


Figure 5a.3 - (a) Total number of SCR peaks of all subjects for the manoeuvres on the T-junctions and for the manoeuvres on the roundabout; (b) average amplitude of SCR peaks of all subjects for the manoeuvres on the T-junctions and for the manoeuvres on the roundabout.

Table 5a.2 – Intersection Impact Factors for roundabouts and for T-junctions.

Intersection Type	*Average amplitude of SCR peaks*	*Number of SCR peaks*	*Electrodermal Impact Index*
Roundabout	1.132	58	65.66
T-Junction	1.083	29	31.41

5a.4 Discussion and conclusion

Roundabouts strategically modify the built environment to affect traffic speed and patterns. They can therefore be fully considered part of traffic calming interventions as they influence the users' driving behaviour by inducing a certain level of stress. There is strong evidence of the resulting reduction of speeds, of accidents and of the severity of the accidents themselves. It is even more evident how roundabouts affect drivers' behaviour if a comparison is made between the accident rates of roundabouts and of standard intersections. The present study examined how at grade intersections affect the driving behaviour by comparing the drivers' stress level for roundabouts and standard intersections. The parameter used for estimating the human response to the stress coming from the two different types of intersection was the Electrodermal activity (EDA) measured on a sample of 19 drivers while driving two crossing manoeuvres on a roundabout and two crossing manoeuvres on two standard intersections. The finding showed that the number of SCR peaks as well as the amplitude of the peaks are overall higher for the two manoeuvres on the roundabout. The stress level induced by each type of intersection was evaluated through an Electrodermal Impact Index which takes into account both the number and the amplitude of SCR peaks. The results are particularly interesting as they suggested that the stress level induced by roundabouts is more than double that induced by standard intersections. Therefore, this research has enabled us to quantify the positive effects of roundabouts in terms of safety through an approach that allowed to evaluate different type of at grade intersections taking into account a parameter directly linked to the human factor. That is a confirmation of a lot of studies demonstrating that safety perception for roundabouts is higher than intersections at grade (Leonardi et al., 2019, Gross et al., 2013). Human factors, which are broadly recognized as the main cause in determining road accidents, can be further examined by means of other indicators of the drivers' stress level. Physiological signals are indeed a useful metric for providing feedback about a driver's state. In this paper the authors analysed only the Electrodermal activity of the drivers to evaluate their physiological and behavioural responses to different intersections.

Further studies will deepen the correlations between different at grade intersections and other physiological parameters, such as blood volume pulse, heart rate and heart rate variability, which were measured during the same experiment on which this study is based.

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5b Mining of the association rules between driver electrodermal activity and speed variation in different road intersections

5b.1 Introduction

One of the solutions for improving road safety both in cities and in rural areas is the design of roundabouts and the conversion of crossroads in roundabouts. Especially single-lane roundabouts are pointed as an example of a very safe intersection when compared to not-signalized and signalized at-grade intersections (Ziolkowski, 2014). The installation of roundabouts has therefore become a popular and effective way to improve road safety. Several previous studies proved that appropriately designed roundabouts can be safer and more efficient when compared to conventional intersections (De Brabander and Vereeck, 2007; Hyden and Varhelyi, 2000). Converting standard intersections to roundabouts has been found to reduce the number of accidents, in particular fatal accidents (Elvik, 2003; Persaud et al., 2001; Vujanić, 2016). Studies of roundabouts in various countries have shown that roundabouts can significantly improve functional characteristics (Easa and Mehmood, 2006; Ma et al., 2013), as well as traffic safety (Chen et al., 2013; Gross et al., 2013). Roundabouts have also been showed to be well accepted by drivers (Retting et al., 2002; Distefano et al., 2019). Several researchers have examined the relationship between geometric elements and safety benefits in roundabouts (e.g. Daniels et al., 2010, Distefano et al., 2018, Leonardi et al., 2019). Safety benefits of roundabouts include lower number of conflict points, elimination of right-angle and turn-left head-on crashes as well as lower approaching speeds which provides more time to react to potential conflicts. Roundabouts affect drivers' behaviour forcing them to reduce speed in order to drive properly on the circulatory roadway. This significantly reduces the crash severity. For this reason, roundabouts are often used as a traffic calming measure in residential areas.

While previous studies investigated the benefits of converting junctions into roundabouts with respect to crash rates and traffic conditions, to the best of the authors' knowledge, few studies analysed how drivers' stress level change between standard intersections and roundabouts (e.g. Distefano N. et al 2019). Research on user behaviour and perceptions can be a helpful tool for improving road safety and accident prevention. There is therefore the need to deepen the human interactions with the road environment for different intersections. This study intends to contribute for a better understanding of drivers' behavioural and physiological responses when approaching T-junctions and roundabouts.

One of the main indicators of drivers' behavioural responses is the speed. Several studies analysed speed variations at intersections (e.g. De Ceunynck et al., 2013). The main cue for speed perception is information derived from the optic flow field, which is perceived with peripheral rather than foveal vision (RIPCORD ISEREST Project, 2006). In other words, the driver perceives speed based on the information (stimuli) present at the roadside. By giving the road user the impression of a higher speed in order to make them slow down, the environment should be enriched with objects. For instance, within built up areas short urban spaces with roundabouts will decrease the speed by influencing the drivers' choice and widen their angle of view for detecting the behaviour of other road users especially the vulnerable. Cavallo and Cohen (2001) pointed out that the size of visual field is a factor, which significantly affects speed perception and correct speed estimation is significantly reduced when the size of the visual field and thus peripheral vision is diminished. Speed choice of the driver also depends on the field of view as well as the fixation point. The further away the fixation point is, the narrower the lateral field and the higher the driving speed will be. It should be also noted that drivers tend to underestimate the speed of other vehicles and overestimate the distance of oncoming cars. This limitation affects manoeuvres such as overtaking or crossing (Borsos et al., 2015).

Physiological signals are a useful metric for providing feedback about a driver's state because they can be collected continuously without interfering with the driver's task performance or the drivers' perception of the road. When humans are subjected to stressors, such as those resulting from a significant workload during driving activity, they tend to show a variety of physiological responses such as pupil dilation, increased heart rate, slowed digestion, and a constriction of blood vessels, mechanisms that are collectively known as the 'fight-or-flight' response (Cain, 2007; Wickens et al., 2004). Measuring drivers' physiological responses during periods of effort investment in simulators and real vehicles has been a subject of investigations for several decades. Examples include physiological measurements during the presence/absence of a secondary task (Mehler et al., 2009), as a function of road infrastructure (Dijksterhuis et al., 2011), or for different levels of automated driving (De Winter et al., 2014). The Autonomic Nervous System (ANS), responsible for involuntary activities, is made up of the Sympathetic and Parasympathetic nervous systems. Stressful events or emergency situations cause dynamic changes in ANS, where the activity rate in the Sympathetic Nervous System (SNS) increases and the Parasympathetic Nervous System (PNS) activity decreases. Alternatively, activities in the PNS dominate during resting activities. SNS and PNS regulate the electrodermal activity, heart rate variability, and brain waves, which are the main measures for stress reported in literature, and other physiological systems including blood pressure.

Electrodermal activity, also known as galvanic skin response or skin conductance, is a reliable indicator of stress (Seyle, 1956). Electrodermal activity (EDA) refers to the variation of the electrical properties of the skin in response to sweat secretion. The whole mechanism is controlled by the sympathetic nervous system and can be used to control the functionality of the cognitive system. By applying a low constant voltage, the change in skin conductance (SC) can be measured non-invasively (Fowles et al.,1981). The time series of SC can be categorized into two components: tonic (i.e., skin conductance level; SCL) and phasic components (i.e., skin conductance response SCR) that have different time scales and relationships to external stimuli (Cacioppo et al., 2007). Specifically, SCR is a useful index of an individual's perceived risk. SCR could be a useful indicator of activities of the sympathetic branch of the autonomic nervous system because the sweat glands are innervated by the sympathetic nervous activities (Poh et al., 2010). The sympathetic arousal stimulated by external stressors is reflected by a higher SCR. In this sense, EDA has been used to understand an individual's mental status related to sympathetic arousal (e.g., stress, attention, risk perception, etc.) in various situations such as occupational settings, human-computer interaction, traffic and automation, and marketing and product evaluation (Boucsein, 2012). SCR could be a more useful index of the perceived risk than other physiological signals such as heart rate, respiration rate, and skin temperature because SCR is the only autonomic physiological variable that is not contaminated by the parasympathetic branch of the autonomic nervous system (Braithwaite et al., 2013).

This paper presents a method for measuring and quantifying drivers' overall stress and behaviour in a real environment using physiological signals and speed variations. Drivers' physiological and behavioural responses when approaching T-junctions and roundabouts are evaluated and analysed. The ultimate aim is to understand how at grade intersections affect the driving behaviour by comparing speed and electrodermal activity variations. The data related to a driving experiment carried out by 20 participants at 3 at-grade intersections (1 roundabout and 2 T-junctions) are used. The association Rule with the Apriori algorithm is used to evaluate associations between the variables related to electrodermal activity, i.e. the number and amplitude of the SCR peaks, and the variables related to speed, i.e. the speed variation and its sign (positive or negative), for each intersection type.

5b.2 Data and method

5b.2.1 Experiment design

The results of an experimental investigation which aimed to explore and capture the user's natural behaviours in the real-world were used in order to evaluate drivers' physiological and behavioural responses when approaching standard intersections and roundabouts. The experiment was part of the "HumanDrive" project. The "HumanDrive" project goal is to develop driverless vehicle technologies that can deal with varied UK driving scenarios in a more humanlike way.

Twenty-three staff members were recruited from Cranfield University, three individuals participated within pilot trials and twenty individuals participated within the trials. An advert was placed on the Cranfield University website, and participants who showed interest were sent an email which included information about the study and a participant recruitment questionnaire. The questionnaire data was used to determine the appropriate participant sample and participants were invited to participate within the study. The twenty participants involved within the trial were evenly divided between males and females. Participants were aged twenty-eight to fifty years of age. They were required to have held a driving license which would be valid in the UK for a minimum of three years. One participant was excluded from the analysis because of a problem during the data collection. The final sample therefore consisted of nineteen participants (ten males and nine females).

An ethics application was made for the experiment to the Research Ethics committee at Cranfield University and received approval. Participants gave their informed consent to take part in the experiment. They were informed that all information collected would have been dealt with in the strictest confidence and would have only been used for research purposes. Participants were also informed that they would not been judged as for their ability as drivers and that the only aim of the study was to analyse the behaviour of a group of drivers to draw conclusions about drivers in general.

The ego vehicle driven by the participant was a Nissan Leaf. The vehicle was instrumented with four colour cameras (one forward facing, one driver facing, one

steering wheel facing, one feet facing) and an OXTS RT1003 vehicle localization system. The RT1003 is a small GNSS-aided inertial navigation system for use in automotive applications where space and payload are restricted. It is designed to measure position, speed and orientation and output those measurements in real-time as well as logging them internally. Utilizing dual antennas, DGPS corrections, tight-coupling and advanced processing technology, the RT1003 delivers up to 2 cm position and 0.1° heading accuracy (2 m antenna separation) with up to 250 Hz output for all measurements. Specifically, the instrument measures:
Vehicle position (latitude and longitude or distance from an agreed reference zero).

- Vehicle position (latitude and longitude or distance from an agreed reference zero).
- Forward speed (assuming flat plane).
- Linear acceleration (X, Y, Z, SAE vehicle coordinates).
- Angular rates about the vehicle axes.
- Vehicle heading.
- Attitude (roll, pitch, yaw).
- GPS time (time duration from age to be agreed).

An Empatica E4 (Empatica Inc., Cambridge, MA, USA) wrist band sensor was worn by the participants to collect physiological data. The wristband embeds four sensors: EDA, photo-plethysmograph, thermometer, and accelerometer. The E4 wristband EDA sensor uses the exosomatic method, which measures skin conductance (μS) by applying a small external current. The sampling frequency of the EDA sensor is 4 Hz (i.e., four samples per second). Participants wore the wristband on their right wrist. The instrument was used to record EDA continuously and unobtrusively during the experiment.

The study involved time for the participants to familiarize themselves with the vehicle, participant 'within trial' data collection, followed by interviews to further understand their driver behaviour. Before the drive could be carried out the participant had to be familiar with the vehicle and how to control it. The ego vehicle dimensions, operation and automatic and electric drive train may be new to the participant. Therefore, a tutorial was provided to explain how the vehicle works, whilst the vehicle was stationary. Moreover, a familiarization period was built into the study to ensure that participants had adequate time to get familiar with the vehicle and a similar level of familiarization was achieved across all participants to prevent experimental bias. The familiarization drive was accompanied by a facilitator, sitting in the back of the vehicle behind the driving seat and issuing directions. The facilitator had to confirm during and/or at the end of the familiarization drive that the participant was confident driving. After this phase the driving study started. Participants were asked to drive naturally. As with the familiarization drive, directions were issued by the facilitator who was sat directly behind the driver's seat. Trials took place between 9am and 4pm, to ensure similar and bright visibility and to avoid busy commuter traffic. When adverse weather such as heavy rain, wind or snow were experienced, the trial was postponed.

5b.2.2 Study area

The driving study took place on the MUEAVI (Multi-User Environment for Autonomous Vehicle Innovation) test environment based at Cranfield University and surrounding roads. MUEAVI is a controlled and instrumented stretch of road, located on the edge of the University Campus. Both public roads and campus roads link to the MUEAVI facility, these roads were also incorporated within the trial, particularly to further assess interactions with the roundabouts and intersections. Figure 5b.1 shows the study location and the driving route. It can be seen the driving route composed by the loop around Cranfield and the MUEAVI (central quadrant) and the familiarization drive (upper left quadrant). Participants drove the route multiple times continuously and therefore they made different manoeuvres through the different intersections situated on the driving route.

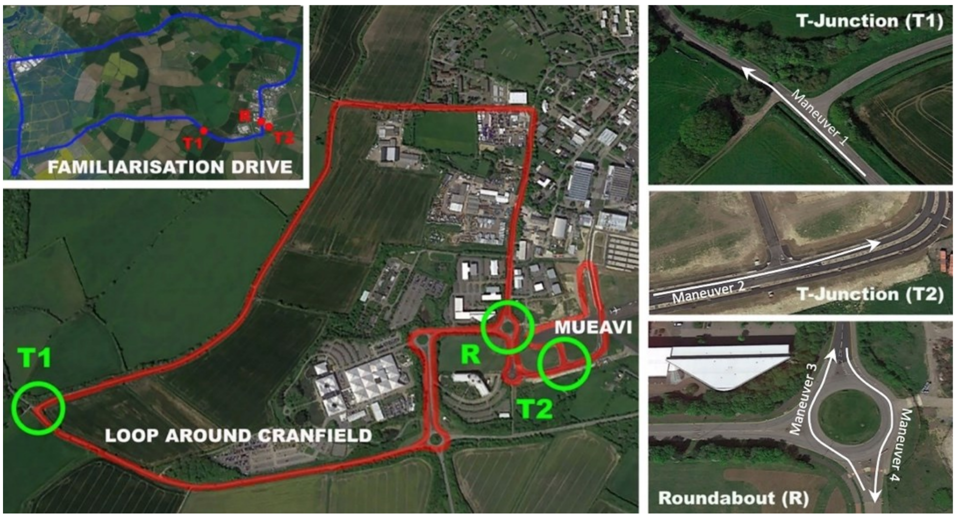

Figure 5b.1 - Study area.

The present study focuses on drivers' electrodermal activity and speed variation when approaching three intersections situated on the study location. These intersections are the roundabout R and the two T-junctions T1 and T2 shown in Figure 5b.1. The roundabout has three perpendicular legs and a diameter of approximately 45 meters. The T-junctions have three legs perpendicular to each other and have similar dimensions.

The analysis regards the drivers' behavioural and physiological responses during a crossing manoeuvre for each T-junction (manoeuvre 1 and manoeuvre 2) and during two crossings manoeuvres on the roundabout (manoeuvre 3 and manoeuvre 4). We chose to compare crossing manoeuvres, rather than turning right or turning left manoeuvres, because the speed for crossing manoeuvres is higher than for other manoeuvres. Since the final aim of the study was to evaluate how the type of intersection affects drivers' risk perception, we analysed only the manoeuvres where the traffic was not affecting the driving behaviour (no traffic or really low traffic at the intersection during the execution of the manoeuvres).

5b.2.3 Speed evaluation

In order to evaluate drivers' speed variation when approaching the intersections, a speed profile was built for each manoeuvre for each participant. The speed profiles were calculated considering the spatial interval where there is a speed variation due to the presence of the intersection. Figure 5.b2 shows operating speeds of typical vehicles approaching and negotiating a roundabout (FHWA, 2000). Approach speeds of 40, 55, and 70 km/h about 100 m from the centre of the roundabout are shown. Deceleration begins approximately at this distance with circulating drivers operating about at the same speed on the roundabout. The relatively uniform negotiation speed of all drivers on the roundabout means that drivers are able to more easily choose their desired paths in a safe and efficient manner.

Starting from this result, the speed profiles were built based on the following considerations: 1) 100 meters before the roundabout can be considered as the distance where drivers begin to vary their speed due to the presence of the intersection; 2) the centre of the intersection can be considered as the point where the driver reach a constant circulating speed; 3) 100 meters after the roundabout can be considered as the point where the driver reach a higher constant speed after accelerating while exiting the roundabout.

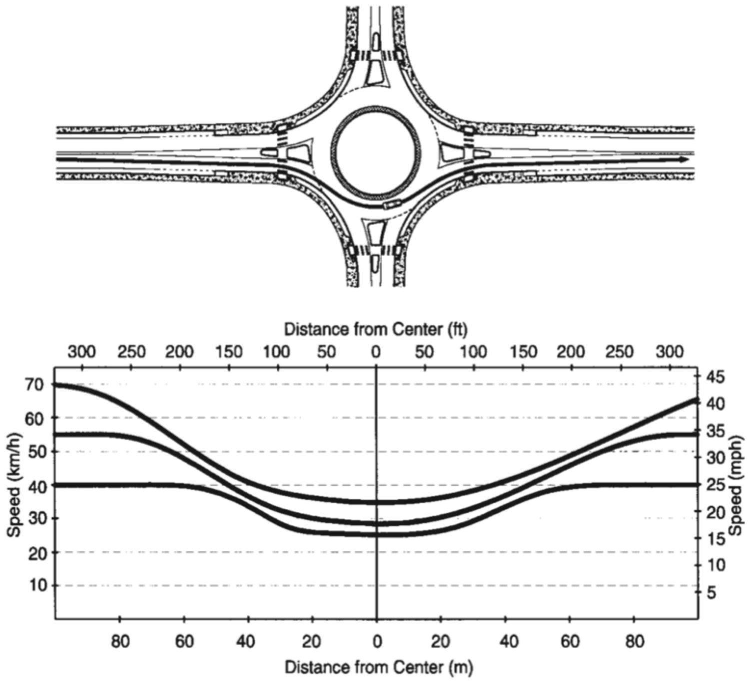

Figure 5b.2 - Sample theoretical speed profile (FHWA, 2000)

The spatial interval corresponding to 100 m before and 100 m after the centre of the intersection was therefore considered for calculating the speed profiles both for the roundabout and for the two T-junctions.

QGIS 3.6 open source software was used to identify the spatial interval corresponding to 100 m before and 100 m after the centre of each intersection starting from the GPS traces. For each of the 4 manoeuvres examined, two speed variations were calculated, both expressed as a percentage: 1) the speed variation ΔS_{100_0} between 100 m before the centre of the intersection and the centre of the intersection; 2) the speed variation ΔS_{0_100} between the centre of the intersection and 100 m after the intersection centre.

5b.2.4 Electrodermal activity evaluation

The tonic level of electrodermal activity, known as skin conductance level (SCL), slowly varies and changes slightly on a time scale of tens of seconds to minutes. The SCL changes for an individual respondent, depending on their hydration, skin dryness, or autonomic regulation. The tonic level can also differ markedly across individuals. This has led some researchers to conclude that the actual tonic level on its own is not that informative (Braithwaite et al., 2013). The phasic response rides on top of the tonic changes and shows significantly faster alterations. Variations in the phasic component are visible as EDA peaks. The phasic response is also labelled skin conductance response (SCR) as it is sensitive to specific emotionally arousing stimulus events (event-related SCRs, ER-SCRs). These bursts occur between 1-5 seconds after the onset of emotional stimuli. By contrast, non-specific skin conductance responses (NS-SCRs) happen spontaneously in the body at a rate of 1-3 per minute and are not a consequence of any eliciting stimulus. SCRs may reflect stimulus-specific responses or non-specific responses. An SCR shows a steep incline to the peak and a slow decline to the baseline. The succession of SCRs usually results in a superposition of subsequent SCRs, as more often than not, a subsequent SCR occurs during the decay of a previous one. Hence SCR does not show distinct peaks of phasic activity, but rather is characterized by the superposition of extended responses, which eventually complicates the assessment of responses (Boucsein, 2012).

Continuous decomposition analysis (Benedek and Kaernbach, 2010) was used in this study for extracting SCRs peaks, as it enables separate detection of superimposed responses. The data were therefore, analysed by determining the number of peaks in the skin conductance response (SCR) that participants had while driving on each intersection through the following procedure. The phasic data (SCR) was extracted from the EDA signal by using a median filter. For each sample, the median EDA score of the surrounding samples was calculated based on a +/- 4 seconds interval centred on the current sample. This value was then subtracted from the current sample to obtain the phasic data. Peak onset/offset thresholds were set to 0.01 μS and 0 μS respectively (Benedek and Kaernbach, 2010). The peak onset value represents the starting point in time where a peak is detected, while the offset value represents the time when a peak has passed. To avoid false positives, the onset value was not counted if it is less than 0.01 μS. The maximum original EDA data within each pair of onsets and offsets is an SCR peak. SCR peak amplitude is the amplitude at the peak minus the amplitude at onset. A peak was only considered if its amplitude was higher than 0.005 of the onset value. Also, a signal jump threshold that accounts for false peaks - caused by noise - is set to 0.02 μS. After continuous decomposition analysis, onsets for each individual SCR were obtained. Onsets served as the basis to subsequently calculate the number of SCR peaks and their amplitude. SCR amplitude rate (i.e. the amplitude at the peak divided the amplitude at the onset) was then calculated for each peak. Based on the values of the SCR amplitude rate, SCR peaks were divided into *high peaks* (amplitude rate higher than 1,1) and *low peaks* (amplitude rate lower than 1,1). SCR peaks were evaluated using a moving window approach with the temporal interval corresponding to 100 m before and 100 m after each intersection, already identified for the analysis of speed.

5b.2.5 Association rule mining

The Association Rule with Apriori algorithm was used in order to find associations between drivers' electrodermal activity (EDA) and speed variations when approaching the intersections studied. The variable related to electrodermal activity is *SCR Peaks* (*SP)*, which takes into account the number and the amplitude rate of SCR peaks when approaching the intersection, i.e. between 100 m before the intersection and the centre of the intersection. The variables related to speed are: *Speed Variation (SV)*, which takes into account the speed variation ΔS_{100_0}, i.e. the speed variation between 100 m before the intersection centre and the intersection centre; *Sign of speed variation (SSV)*, which takes into account the sign of the speed variation ΔS_{100_0} (positive or negative).

The speed and electrodermal activity data are related to a crossing manoeuvre for the T-junction T1 (maneuver1), a crossing manoeuvre for the T-junction T2 (manoeuvre 2) and two crossing manoeuvres for the roundabout R (manoeuvres 3 and 4). In order to evaluate how the type of intersection affect electrodermal activity and speed variations, the variables *SCR Peaks* (*SP), Speed Variation (SV)* and *Sign of speed variation (SSV)* were considered for each type of intersection. The *Intersection Type Roundabout (ITR)* therefore, groups together manoeuvre 3 and manoeuvre 4, while the *Intersection Type T-junction (ITT)* groups together manoeuvre 1 and manoeuvre 2.

Table 5b.1 shows the variables used for the Association Rule with Apriori algorithm and the items considered for each variable.

Apriori algorithm AR is one of the most popular data mining techniques, first introduced in 1993 for discovering buying patterns (Agrawal, et al. 1993). In recent years, the AR method in data mining has been successfully applied to uncover potential patterns or rules in a variety of fields, such as road traffic safety (Montella, 2011; Wu et al. 2019; Prati et al. 2017). AR analysis is the method of effectively identifying sets of items that occur together in a given event. It is based on the relative frequency of the number of times the sets of items occur alone and jointly in a database. AR is a standard approach that starts with a dataset containing transactions and aims to construct frequent item sets by setting up a user specified thresholds, namely Support, Confidence, and Lift.

Table 5b.1 - Items of the variables for Association Rule

IT – Intersection Type	*SP – SCR Peaks*	*SV – Speed Variation*	*SSV - Sign of the Speed Variation*
ITR = Roundabout	SP0 = No Peak	SV0 = Up to 10 %	SSVP = Positive sign (speed increase)
ITT = T-Junction	SP1 = 1 Low Peak	SV1 = Between 10 % and 20 %	SSVN = Negative sign (speed reduction)
	SP2 = 1 High Peak	SV2 = Between 20 % and 30 %	
	SP3 = At least 2 peaks (all low)	SV3 = Between 30 % and 40 %	
	SP4 = At least 2 peaks (at least one high peak)	SV4 = Between 40 % and 50 %	
		SV5 = Over 50 %	

The Support (S) for a particular association rule A ⇒ B is the proportion of transactions in the database containing both A and B and is formulated as equation [1]:

$$Support(A \rightarrow B) = \frac{P(A \cap B)}{N} = \frac{number\ of\ transactions\ containing\ both\ A\ and\ B}{total\ number\ of\ transactions} \quad [1]$$

The Confidence (C) of the association rule A ⇒ B is a measure of the accuracy of the rule, which is determined by the percentage of transactions in the database containing A that also contains B and is defined as equation [2]:

$$Confidence\ (A \rightarrow B) = \frac{P(A \cap B)}{P(A)} = \frac{number\ of\ transactions\ containing\ both\ A\ and\ B}{number\ of\ transactions\ containing\ A} \quad [2]$$

Lift (L) is defined as a simple correlation that measures if A and B are independent or dependent and correlated events and is expressed by the equation [3]:

$$Lift\ (A \rightarrow B) = \frac{P(A \cap B)}{P(A)P(B)} = \frac{number\ of\ transactions\ containing\ A\ or\ B}{number\ of\ transactions\ containing\ A\ x\ number\ of\ transactions\ containing\ B} \quad [3]$$

If a particular rule has a Lift of one, it indicates that the probabilities of A and B are independent. When two events are independent, there is no rule drawn involving these two events. In contrast, if a particular rule has a Lift greater than one, it indicates A and B are dependent and positively correlated. The higher the Lift, the greater is the strength of the association rule.

It is desirable for the rules to have a large Confidence factor, a high level of Support, and a Lift value greater than one. Since some events of interest in this analysis are low frequency (e.g., ‘‘SP1 = 1 Low Peak” or "SV3 = Speed Variation between 30% and 40%"), the Support for some rules of interest could be quite low. It essentially means that the Lift value is more important for determining the strength of an association rule than the other two criteria.

Hence, in the present application the rules will be evaluated based on the Lift values. It is not to say that the other two criteria are of no importance. The rules discovered by the algorithm still need to have Support greater than a minimum threshold. The threshold, however, will have to be set lower (but in any case, at least 5%) compared to a marketing application (Pande and Abdel-Aty, 2009). The threshold ensures that the pattern identified by a rule is observed in the database with at least some reasonable frequency. If one only relies on the Lift value and not use a threshold for minimum Support it is possible to identify rules based on very few cases. These rules would be of little practical value.

The parameter Confidence provides a measure for how confident one can be of the fact that a given condition occurs in one of the two types of intersections considered. Confidence is especially important when dealing with characteristics that always exist or with high probability, such as "SV0 = Speed Variation up to 10%" (68.42%) in T-junctions or as "SP4 = At least 2 peaks (at least one high peak)" (85,71%) in roundabouts.

Specifically, to identify strong associations, threshold values for Support, Confidence, and Lift were set as follows: S ≥ 5%, C ≥ 50%, and L ≥ 1. Analyses were performed using the software SPSS Modeler.

5b.3 Results and discussion

5b.3.1 Analysis of EDA profiles

Electrodermal activity profiles for the interval corresponding to 100 m before and 100 m after the centre of each intersection were obtained for all participants for each of the 4 crossing manoeuvres. Figure 5b.3 shows an example of EDA trend (participant 9, manoeuvre 1 and manoeuvre 3). Electrodermal activity is expressed in microsiemens (μS) while the distance from the intersection centre is expressed in meters (m). It can be seen that there is not a substantial EDA variation for the T-junction T1 (manoeuvre 1). For the roundabout, instead, the driver manifests a significant physiological reaction in approaching the intersection, as evidenced by the EDA values which oscillate approximately between 0.3 μS and 0.35 μS. Furthermore, in proximity of the centre of the roundabout there is a reduction of EDA with values around 0.25 μS.

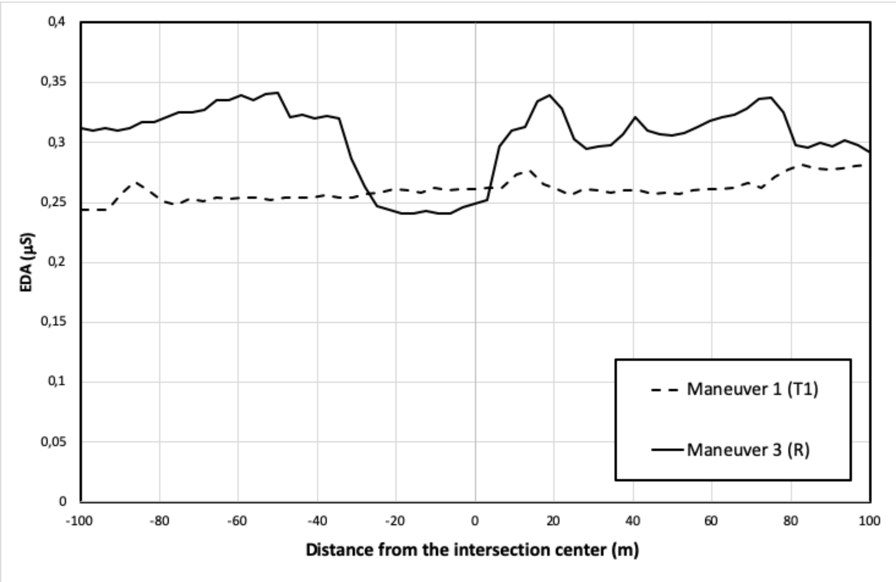

Figure 5b.3 - EDA trends for participant 9 during manoeuvre 1 (T-junction T1) and manoeuvre 3 (Roundabout R).

Table 5b.2 shows the SCR peaks amplitude of all participants during each crossing manoeuvre on the two T junctions (manoeuvres 1 and 2) and during each crossing manoeuvre on the roundabout (manoeuvres 3 and 4). Table 5b.2 also distinguishes the peaks that occurred approaching the intersection (i.e. between 100 meters before the intersection centre and the intersection centre) from those that occurred after (i.e. between the intersection centre and 100 meters after the intersection centre).

Table 5b.2 - SCR peak distribution of all participants during each crossing manoeuvre on the two T-junctions (T1 and T2) and during each crossing manoeuvre on the roundabout (R)

	T-Junctions				*Roundabout*			
	Manoeuvre 1 (T1)		*Manoeuvre 2 (T2)*		*Manoeuvre 3 (R)*		*Manoeuvre 4 (R)*	
Participant	*SCR Peaks amplitude*	*Peaks 100 m - centre*	*SCR Peaks amplitude*	*Peaks 100 m - centre*	*SCR Peaks amplitude*	*Peaks 100 m – centre*	*SCR Peaks amplitude*	*Peaks 100 m - centre*
1	1,069	Yes	-	-	1,125	Yes	1,090	Yes
	-	-	-	-	1,276	Yes	1,414	Yes
	-	-	-	-	1,532	Yes	-	-
2	1,004	No	1,088	Yes	1,020	Yes	-	-
	-	-	-	-	1,005	No	-	-
3	1,004	Yes	1,005	Yes	1,002	Yes	1,085	Yes
	-	-	-	-	1,134	Yes	1,120	Yes
4	-	-	-	-	1,054	Yes	1,192	Yes
	-	-	-	-	1,014	Yes	1,051	Yes
5	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	1,015	Yes
7	1,017	Yes	1,007	Yes	1,320	Yes	1,660	Yes
	-	-	-	-	1,110	Yes	-	-
	-	-	-	-	1,209	Yes	-	-
8	1,004	No	-	-	1,001	Yes	1,098	Yes
	-	-	-	-	1,155	No	-	-
9	1,009	Yes	1,023	Yes	1,042	Yes	1,053	No
	-	-	-	-	1,142	Yes	1,040	No
	-	-	-	-	1,060	Yes	-	-
10	1,029	Yes	-	-	1,014	Yes	-	-
11	1,025	Yes	1,016	No	-	-	-	-
12	1,213	Yes	1,180	No	1,400	Yes	1,110	Yes
	-	-	-	-	1,072	Yes	-	-
13	1,333	No	-	-	1,162	Yes	1,036	Yes
14	1,006	Yes	-	-	1,017	Yes	1,016	Yes
	-	-	-	-	1,034	No	-	-
15	1,027	Yes	-	-	-	-	1,045	No
16	1,099	Yes	1,228	Yes	1,257	Yes	1,121	Yes
	1,240	Yes	1,117	Yes	1,090	Yes	1,067	Yes
	1,305	Yes	-	-	1,049	Yes	1,220	Yes
	-	-	-	-	1,036	No	1,033	No
17	1,048	Yes	1,137	Yes	1,214	Yes	1,018	Yes
	1,006	Yes	-	-	1,004	Yes	-	-
18	1,006	Yes	1,011	Yes	1,041	Yes	1,289	Yes
	-	-	-	-	1,008	No	1,009	Yes
	-	-	-	-	-	-	1,291	No
19	1,180	Yes	-	-	1,288	Yes	1,103	Yes
	-	-	-	-	1,245	No	1,296	Yes

From the analysis of Table 5b.2 it can be seen that thirteen out of nineteen participants had more SCR peaks during the manoeuvres on the roundabout rather than during the manoeuvres on the T-junctions; ten of them also had a higher amplitude of the peaks during the manoeuvres on the roundabout. Eleven out of nineteen participants show a higher amplitude of the SCR peaks during the manoeuvres on the roundabout. Four participants had the same number of peaks during the manoeuvres on the roundabout and during the manoeuvres on the T-junctions. One participant (participant 5) did not show any peak at all. Only one participant had more SCR peaks during the manoeuvres on the T-junctions rather than during the manoeuvres on the roundabout (participant 11). The number of SCR peaks as well as the amplitude of the peaks are overall higher for the manoeuvres on the roundabout (number of peaks: 58 for roundabout, 29 for T-junctions; medium amplitude of peaks: 1,132 for the manoeuvres on the roundabout, 1,083 for the manoeuvres on the T-junctions. Over 80% of the SCR peaks occurred in approaching the intersections, i.e. between 100 meters before the intersection centre and the intersection centre.

24 peaks out of 29 occurred in approaching the T-junctions and 47 peaks out of 58 occurred approaching the roundabout. These results can be interpreted for increased anxiousness (higher emotional response) with respect to baseline (Villarejo et al. 2012), with more impact in the roundabout.

5b.3.2 Analysis of speed profiles

Speed profiles for the interval corresponding to 100 m before and 100 m after the centre of each intersection were obtained for all participants for each of the 4 crossing manoeuvres. Figure 5b.4 shows an example of speed profile (participant 9, manoeuvre 1 and manoeuvre 3). It can be seen that the approach speed variation in the case of the T-junctions (manoeuvre 1) is very low: the speed remains almost constant, approximately equal to 52 km h, between 100 m before the intersection centre and the intersection centre. As for the roundabout (manoeuvre 3), instead, the speed is equal to 35 km/h 100 m before the intersection centre and goes down to approximately 28 km/h at the intersection centre. The approach speed decreases therefore by 21% approximately between 100 m before the intersection centre and the intersection centre.

Table 5b.3 shows the speed variations ΔS_{100_0} and ΔS_{0_100} evaluated for each manoeuvre.

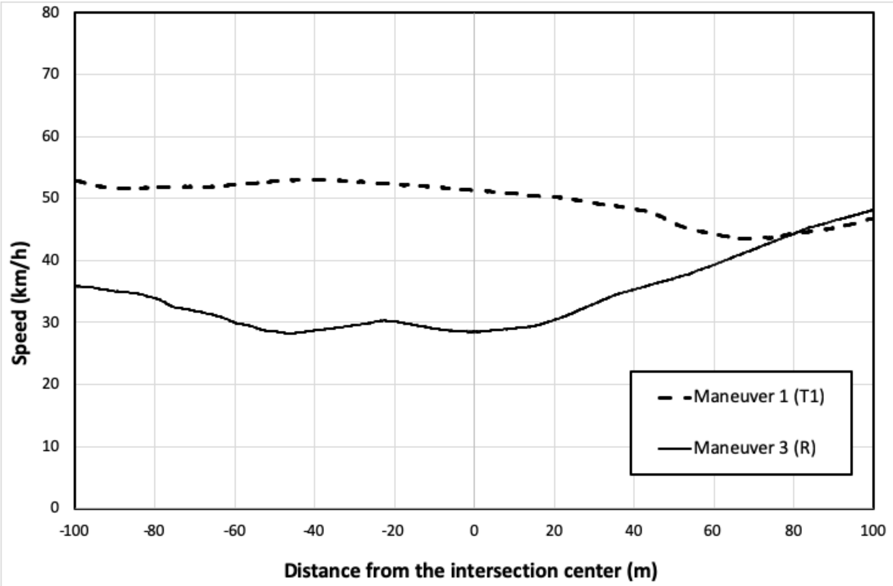

Figure 5b.4 - Speed profiles for participant 9 during manoeuvre 1 (T-junction T1) and manoeuvre 3 (Roundabout R).

It can be seen that the drivers' behaviour in terms of speed variation when approaching the intersections (ΔS_{100_0}) is really different for T-junctions and roundabouts. 4 drivers out of 19 increase their speed approaching the T-Junction T1. 16 drivers significantly increase their speed approaching the T-Junction T2. Drivers' increases of speed when approaching intersection T2 could be due to the fact that they are exiting a roundabout and they are entering onto the straight road on MUEAVI. Anyway, the presence of the T-junction T2 does not induce drivers to reduce their speed.

As for the roundabout, only 3 drivers increase their speed approaching the roundabout during manoeuvre 3 and all drivers significantly reduce their speed approaching the roundabout during manoeuvre 4. These results confirm the well-known vocation of the roundabouts as traffic calming measures. By contrast, the T-junctions analysed shows modest reductions in the approach speed and, at the same time, dangerous increases in the approach speed.

As for the speed variations ΔS_{0_100}, it can be seen that all 19 drivers significantly increase their speed leaving the roundabout during manoeuvre 3 and almost all drivers increase their speed leaving the roundabout during manoeuvre 4 (only 3 drivers decrease their speed). For the two T-Junctions several drivers decrease their speed leaving the intersection, with speed variations higher than 15%. This is probably due to the road geometry which, immediately after both T-junctions, has curvilinear sections that induce users to slow down.

Table 5b.3 - Speed differences distribution of all participants during each crossing manoeuvre on the two T-junctions (T1 and T2) and during each crossing manoeuvre on the roundabout (R)

	T-Junctions				*Roundabout*			
	Manoeuvre 1 (T1)		*Manoeuvre 2 (T2)*		*Manoeuvre 3 (R)*		*Manoeuvre 4 (R)*	
Participant	*ΔS100_0 (%)*	*ΔS0_100 (%)*	*ΔS100_0 (%)*	*ΔS0_100 (%)*	*ΔS100_0 (%)*	*ΔS0_100 (%)*	*ΔS100_0 (%)*	*ΔS0_100 (%)*
1	+15,9	+14,4	+14,6	-13,9	-26,2	+80,4	-38,3	+37,4
2	-15,7	-14,6	+42,4	-4,3	-22,2	+57,9	-30,8	+25,9
3	-6,6	-16,7	-14,5	+13,8	-22,5	+58,4	-34,3	+37,9
4	-13,5	-14,2	+20,2	-15,8	-15,8	+44,4	-12,2	-2,4
5	-4,0	-25,1	+32,3	-7,7	-4,1	+48,8	-21,3	+0,2
6	-5,3	-10,7	+28,3	-12,6	-25,6	+48,6	-26,2	+13,5
7	-20,6	-3,4	+35,3	-16,6	-8,5	+32,4	-23,4	-5,1
8	-7,9	-15,3	+29,1	-6,7	+11,8	+50,6	-17,9	-11,6
9	-2,9	-8,8	-33,0	+79,8	-20,6	+68,8	-27,0	+7,9
10	+6,0	-19,4	+12,6	-18,4	-15,6	+77,5	-22,4	+13,6
11	-14,0	-4,8	-2,7	32,2	+4,0	+48,8	-28,1	-27,8
12	-10,7	-18,7	+30,7	-14,8	-11,3	+44,3	-32,2	+24,5
13	-13,4	+3,1	+53,3	-6,1	-3,6	+46,7	-17,9	+9,0
14	+2,8	-10,8	+5,2	-19,5	-3,1	+23,5	-23,8	-9,0
15	-4,3	-11,5	+13,1	+3,8	-11,8	+41,0	-18,1	-2,3
16	+0,9	-9,4	+34,0	+2,6	-13,1	+48,2	-51,9	+57,3
17	-31,9	+23,3	+26,4	-10,0	-17,0	+38,6	-16,8	+2,1
18	-10,2	-17,4	+3,6	+8,1	+17,5	+42,6	-49,2	+33,5
19	-14,1	-0,5	+5,6	-12,6	-10,0	+70,8	-38,0	+22,2

5b.3.3 Analysis of association rule mined

Association rule analysis with Apriori algorithm was applied to further investigate drivers' behaviour while approaching different types of at grade intersections. The variable *Intersection Type* was chosen as the consequent result for the AR model to evaluate how the two types of intersection (*Intersection Type T-Junction* ITT and *Intersection Type Roundabout* ITR) affect speed and electrodermal activity of the 19 drivers.

The association algorithm identified 36 rules with Support greater than 5%, Confidence greater than 50%, and Lift greater than 1 (18 rules for *Intersection Type T-Junction* and 18 rules for *Intersection Type Roundabout*).

Table 5b.4 shows the Association Rules having ITT (*Intersection Type T-Junction*) as a consequent result. 2-item, 3-item, and 4-item rules are set out with their Support, Confidence, and Lift values. The rules are ordered on the basis of the Confidence. The strongest link is expressed by rule n. 1 (L = 2, C = 100% and S = 5.263), which associates *Intersection Type T-Junction* (ITT) with the speed increase between 20% and 30%. The strongest link related to the peaks for *Intersection Type T-Junction* (ITT) is expressed by rule n. 4 (L = 1.714; C = 85.714%; S = 9.211%), which associates "1 Low Peak" with the speed variation less than 10%. This highlights that T-junctions poorly affect drivers' psycho-physical conditions and cause at the same time modest speed variations. The low propensity of T-Junctions to induce significant variations in drivers' electrodermal activity is further confirmed by rule n. 2 which defines a very strong association (L = 1.833; C = 91.667%; S = 15.789%) between *Intersection Type T-Junction* (ITT) and "No peak" and "Speed increase". Rule 3, having the same strength as rule n. 4, clarifies that situations in which T-Junctions cause a low variation in speed (less than 10%) are mainly speed increasing. Rule n. 5, while being less strong than the previous rules (L = 1.667 and C = 83.333%), is characterized by a very high Support (31.579%). Considering that this is a 2-Items rule involving the "Positive sign" of speed variation, it is confirmed that drivers do not significantly reduce speed while approaching T-Junctions.

Table 5b.4 - Association Rules for T-Junction

ID Rule	*Consequent*	*Antecedent*	*Support (%)*	*Confidence (%)*	*Lift*
1	ITT	SV2 and SSVP	5,263	100	2
2	ITT	SSVP and SP0	15,789	91,667	1,833
3	ITT	SV0 and SSVP	9,211	85,714	1,714
4	ITT	SV0 and SP1	9,211	85,714	1,714
5	ITT	SSVP	31,579	83,333	1,667
6	ITT	SV3 and SSVP	6,579	80	1,6
7	ITT	SV0 and SP0 and SSVN	6,579	80	1,6
8	ITT	SV0 and SP0	10,526	75	1,5
9	ITT	SSVP and SP1	10,526	75	1,5
10	ITT	SV1 and SP0	10,526	75	1,5
11	ITT	SV0 and SP1and SSVN	5,263	75	1,5
12	ITT	SV0	25	68,421	1,368
13	ITT	SP0	35,526	66,667	1,333
14	ITT	SSVP and SV1	7,895	66,667	1,333
15	ITT	SV1 and SP0 and SSVN	6,579	60	1,2
16	ITT	SP1	31,579	58,333	1,167
17	ITT	SV0 and SSVN	15,789	58,333	1,167
18	ITT	SV3	14,474	54,545	1,091

The first rule in which speed reduction appears is rule n. 7. This is a "4-Items rule" expressing a not strong link with speed reduction less than 10% and “No SCR Peak”. The fact that this rule has the same strength as rule n. 6, which instead associates T-junctions with a considerable speed increasing (between 30% and 40%), shows how speed reduction is not at all a prerogative of T-Junctions.

The rules between n. 8 and n. 18 confirm the peculiarities of T-Junctions expressed more strongly by the first 7 rules. Rules 13 and 16 despite being at the bottom of the ranking for Lift and Confidence values, have the highest Support values (respectively 35.526% and 31.579%). These are "2-Items rule" where “No Peak” and “1 Low Peak” emerge as the most frequent conditions in the drivers’ physiological responses. Considering that “No Peak” is a physiological "non-response" and that “1 Low Peak” is a very low physiological response, this once again highlights that the T-junctions investigated poorly affect drivers’ reactions and consequently have a poor influence on their driving behaviour.

Table 5b.5 shows the Association Rules having ITR (*Intersection Type Roundabout*) as a consequent result. 2-item, 3-item, and 4-item rules are set out with their Support, Confidence, and Lift values. The rules are ordered on the basis of the Confidence. The strongest link is expressed by rule n. 1 (L = 2, C = 100% and S = 14.474) which associates *Intersection Type Roundabout* (ITR) with the speed reduction and with SP4 (“At least 2 peaks, at least one high), i.e. the maximum condition relative to electrodermal activity. Rule n. 4 also expresses a very strong link (L = 1.714; C = 85.714%; S = 18.421%) between drivers’ behaviour on the *Intersection Type Roundabout* (ITR) and SP4 (“At least 2 peaks, at least one high). Rule n. 3 specifies through a very strong link (L = 1.846; C = 92.308%; S = 17.05%) how roundabouts basically cause reductions in approaching speed between 20% and 30%. Rule n. 5 (L = 1.5; C = 75%; S = 5.263%) confirms the association between roundabouts and high electrodermal activity, and also highlights a significant association with high speed variation (between 30% and 40%). Therefore, four rules among the first five express, through the very strong links of the a priori algorithm, how roundabouts affect drivers’ behaviour. Differently from T-Junctions, drivers’ behaviour when approaching roundabouts is strongly associated with the situation of maximum electrodermal activity and with a speed reduction of between 20% and 40%.

Among the first five rules, rule n.2 is a very strong link (L = 2; C = 100%; S = 5.263%) and highlights associations different from the above mentioned. It indeed expresses the association between speed reduction between 20% and 30% and the absence of SCR peaks. This demonstrates that roundabouts induce speed reduction, while not generating significant physiological reactions in all users. However, it should be noted that the value of Support it is not very high, so the combination of the situations described by rule n. 2 is not among the most frequent. Rules n. 6 and n. 7 are characterized by the same parameters (L = 1.5; C = 75%, S = 5.263%). They show the association between speed reduction (between 20% and 30%) and low electrodermal activity (i.e. one peak with low amplitude).

Table 5b.5 - Association Rules for Roundabout

ID Rule	*Consequent*	*Antecedent*	*Support (%)*	*Confidence(%)*	*Lift*
1	ITR	SP4 and SSVN	14,474	100	2
2	ITR	SV2 and SP0 and SSVN	5,263	100	2
3	ITR	SV2 and SSVN	17,105	92,308	1,846
4	ITR	SP4	18,421	85,714	1,714
5	ITR	SV3 and SP4	5,263	75	1,5
6	ITR	SV2 and SP1	5,263	75	1,5
7	ITR	SV2 and SP1 and SSVN	5,263	75	1,5
8	ITR	SP2 and SSVN	9,211	71,429	1,429
9	ITR	SV2	22,368	70,588	1,412
10	ITR	SV3 and SSVN	7,895	66,667	1,333
11	ITR	SSVN	68,421	65,385	1,308
12	ITR	SP2	10,526	62,5	1,25
13	ITR	SP1 and SV2	13,158	60	1,2
14	ITR	SV1 and SSVN	25	57,895	1,158
15	ITR	SV2 and SP0	9,211	57,143	1,143
16	ITR	SP1 and SV1 and SSVN	9,211	57,143	1,143
17	ITR	SP0 and SSVN	19,737	53,333	1,067
18	ITR	SV1	32,895	52	1,04

The rules between n. 8 and n. 18 confirm the peculiarities of roundabouts expressed more strongly by the first 7 rules. Rule n.11 despite being at the bottom of the ranking for Lift and Confidence values, has the highest Support value (68.421%). This is a "2-Items rule" where “Speed reduction” emerge as the most frequent condition in the drivers’ behaviour. Excluding the last two rules of the ranking (rules n. 17 and 18) characterized by very low values of Lift and Confidence, the highest values of the Support is associated to rule n. 9 and to rule n. 4. Rule n. 9 associates roundabouts to speed variation between 20% and 30%. Rule n. 4

associates roundabouts to the maximum electrodermal activity (i.e. at least 2 peaks, at least one high). These two rules highlights how roundabouts are mainly associated with speed reductions of 20% and physiological reactions high in terms of electrodermal activity (EDA).

5b.4 Conclusion

It is acknowledged that roundabouts strategically modify the built environment to affect traffic speed and patterns. The comparison between accident rates of roundabouts and of standard intersections confirms the reduction of speeds, of accidents and of the severity of the accidents themselves in roundabouts (Chen et al., 2013; Polders et al., 2014; Daniels et al., 2011). Roundabouts can therefore be fully considered part of traffic calming interventions as they influence the users' driving behaviour by inducing a certain level of stress. The analysis of speed and electrodermal activity allowed to estimate the human response to the stress coming from the two different types of intersection. The findings of this paper have explicitly confirmed the existence of a link between driving behaviour and physiological parameters. Association rule analysis with Apriori algorithm was applied in order to obtain the rules associating the type of intersection, the number and the amplitude of SCR peaks and the variation of speed. The main results of this study are the following:

1) the rules obtained for the manoeuvres on T-junctions define a very strong association with the absence of SCR peaks (or the presence of few peaks with low amplitude) and the speed increase. Therefore, these rules highlight how T-junctions induce low variations in electrodermal activity and are often associated with a significant speed increase (which was estimated to be between 30% and 40%). It is therefore evident that speed reduction is not at all a prerogative of T-junctions.
2) the rules obtained for the manoeuvres on the roundabout define a very strong association with the condition of maximum electrodermal activity (i.e. lot of peaks with high amplitude) and speed reduction. It is therefore evident that the roundabout strongly affects drivers' behaviour, inducing significant electrodermal activity and speed reductions (mainly between 20% and 40%).

The proposed model has shown that the stress level induced by roundabouts is significantly higher than that one induced by T-junctions. The quantification of the links between speed variations and electrodermal activity enabled to better understand the advantages of roundabouts in terms of safety compared to T-junctions.

Human factors, which are broadly recognized as the main cause in determining road accidents, can be further examined by means of other indicators of the drivers' stress level. Physiological signals are indeed a useful metric for providing feedback about a driver's state. In this paper the authors analysed only the Electrodermal activity of the drivers to evaluate their physiological and behavioral responses to different intersections. Further studies will deepen the correlations between different at grade intersections and other physiological parameters, such as blood volume pulse, heart rate and heart rate variability, which were measured during the same experiment on which this study is based.

5b.5 References

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6. SAFETY OF ROUNDABOUTS WITH MIXED TRAFFIC: A VIDEO ANALYSIS OF BICYCLIST BEHAVIOUR

This chapter makes use of semi-automated video observation software with the aim of analysing bicyclist behaviour and bicyclist safety on roundabouts with different diameters. The motivation for this study is to understand better bicyclist behaviour and how it varies under different conditions. Four four-legs roundabouts with mixed traffic located in Belgium were selected for detailed analysis. Lateral positions and riding speeds of free-flow bicyclists were analysed with regard to several factors (e.g. diameter of the roundabout, helmet use, reflective devices use). Lateral positions and riding speeds of free-flow bicyclists were then compared to the ones of bicyclists who are in interaction with vehicles in order to understand if and how the presence of other road users affects bicyclists' behaviour. Additionally, interactions between bicyclists and vehicles were analysed using surrogate safety indicators (overtaking proximity, time gap and minimum time-to-collision).

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6.1 Introduction

Active modes of transportation such as cycling are promoted as a way to provide health benefits, mitigate traffic congestion and reduce air pollution (Götschi, Garrard, and Giles-Corti 2016). Transport authorities and policy makers continue to encourage people to use sustainable travel modes due to the benefits they offer to society. However, safety and security can be considered as one of the main barriers associated with the use of sustainable travel modes in general, and walking and cycling in particular (Akgün et al. 2018; De Ceunynck et al. 2019). The promotion of cycling brings health benefits for citizens of all age groups and to further favour the use of bicycles, special attention should be dedicated to cycling safety. Infrastructure design plays a major role in creating a safer travel environment for road users.

Although converting an intersection into a roundabout has been shown to result in fewer injury accidents for both motor vehicle drivers and pedestrians (Elvik and Vaa 2009; Hydén and Várhelyi 2000; NCHRP 2007; Retting et al. 2001) the effect on bicyclists' safety is unclear or even negative (Daniels, Nuyts, and Wets 2008; Daniels and Wets 2005; Jensen 2013). Multiple studies have already focused on bicyclists' safety at roundabouts but little is known about the interactions between bicyclists and other road vehicles at roundabouts. Better understanding of how bicyclists move and interact with other vehicles at roundabouts is important for improving bicyclists' safety.

This study focuses on roundabouts without bicycle facilities (roundabouts with mixed traffic) and makes use of semi-automated video observation software with the aim of analysing bicyclists' behaviour and safety on roundabouts with different diameter. The study focuses on roundabouts with mixed traffic because at such roundabouts multiple interactions between bicyclists and motorists can be present as they share the same road. Interactions between bicyclists and other vehicles are analysed using speed, lateral position and surrogate safety indicators (overtaking proximity, distance headway and minimum time-to-collision), and the behaviour of bicyclists who are in interaction with other vehicles is compared with the behaviour of bicyclists who are not in interaction with other vehicles. The influence of bicyclists' sociodemographic and behavioural variables (gender, use of helmet and use of reflective devices) is also evaluated.

6.2 Background

International studies have unanimously demonstrated that the construction of roundabouts is an effective measure to improve road traffic safety. During the last decades several studies were carried out into the effects of roundabouts on traffic safety. In general, roundabouts have a favourable effect on traffic safety, at least for accidents causing injuries. Over the last decades several studies have been carried out on the effects of roundabouts on traffic safety. Lot of studies reported a considerably decrease in the number of accidents in roundabouts compared to standard intersections (De Brabander, Nuyts, and Vereeck 2005; Elvik 2003; Persaud et al. 2001). Less is known about the safety effects of roundabouts for particular types of road users, such as bicyclists (Daniels and Wets 2005). A Belgian study finds that roundabouts increase bicyclist injury accidents by 27% and fatal accidents by 41–46% (Daniels, Nuyts, and Wets 2008). Earlier research showed that signalized junctions were performing better than roundabouts for bicyclists (De Brabander and Vereeck 2007). However, Jensen (2017) stated that in high speed limit locations, converting intersections to single lane roundabouts decreases the number of crashes and casualty severity of bicyclists.

The problem behind bicycle-automobile accidents at roundabouts (and other give-way intersections) seems to be drivers' attention and expectations during approach. Drivers concentrate their attention on the parts of the road and the traffic environments they find most threatening or where they expect relevant objects to be found (Summala 1998; Summala et al. 1996). Motorists tend to look more frequently for major dangers (i.e., automobiles) but ignore less frequent and conspicuous dangers such as bicycles (Räsänen and Summala 2000). Therefore, entering drivers probably fail to see circulating bicyclists because they look for cars rather than bicyclists. Other researchers (Summala et al. 1996) revealed that the approaching speed of an automobile (that is about to enter an intersection) would play a part in the visual scanning strategies of the motorist – higher approaching speed results in the motorist being more likely to scan for a more threatening road user (e.g., a conflicting automobile) but being less likely to allocate much attention to a bicycle. Research has identified these crashes as "looked-but-failed-to-see" accidents in which in many cases the motorist has actually been looking in the direction where the other road user was but has not seen the bicyclist (Herslund and Jørgensen 2003). "Looked-but-failed-to-see" are very common at roundabouts since the approaching traffic needs to give way to the circulating traffic. Aside from the abovementioned contributory factors to bicycle–automobile accidents, inappropriate design features of roundabouts such as inadequate entry deflection and flared entries have also been documented in literature to allow high entry speeds, thereby increasing bicycle accident risks (Hall and Maycock 1984). Engineering measures such as marking bicycle crossing and raised bicycle crossing at junctions are aimed to provide bicycles greater priority, and there have been numerous studies that have investigated the effectiveness of these engineering measures (Hunter et al. 2000; Jensen 2008).

Bicycle safety is influenced by roundabout design. Daniels et al. (2009, 2011) find that roundabouts with marked cycle lanes next to the circulation are less safe for bicyclists than roundabouts without bicycle facilities, and roundabouts with separate cycle paths are safer than roundabouts with no bicycle facilities. Jensen 2017 conducted a comprehensive study on the impact of single lane roundabouts with different sizes of central islands on bicyclist safety and found that single lane roundabouts with a 20–40 m central island were safer than those having a larger or smaller central island radius. Reid and Adams (2011) highlighted that all road infrastructure related factors, such as the number of flare lanes on approach, half width on approach, entry path radius, number of arms, central radius, entry width, number of lanes on approach and type of roundabout are fundamental factors in the decision-making process of how to reduce bicyclist casualties. (Hels and Orozova-Bekkevold 2007) assessed the impact of geometric design features on bicyclist accident occurrence by evaluating ‘drive curve’ (i.e. the entry path radius). They concluded that a higher drive curve (entry path radius) increases the probability of bicyclist accident. (Daniels et al. 2010) stated that increase of age of bicyclist results in an increase in casualty severity at roundabouts for all types of road users; however, the impact of gender is uncertain. In addition, they found that the severity of casualties at roundabouts increased at night and outside of built up areas regardless of the type of road users involved. (Akgün et al. 2018) investigated which design factors influence bicyclist casualty severity at give way (non-signalized) roundabouts with mixed traffic and found that the probability of a serious casualty increases by approximately five times for each additional number of lanes on approach and by 4% with a higher entry path radius.

The interaction between motorized and no motorized road users has been an issue of contention for many years. Indeed, bicyclists and drivers differ significantly from each other in terms of speed, size, weight, and vulnerability, so that interacting with one or the other implies adapting our perceptions and our behaviour to these differences. Bicyclists’ presence on the road is considered annoying by drivers (Basford et al. 2002) and even regarded as a source of danger. On the other hand, bicyclists complain that driver behaviour ranges from dangerous to illegal (Chapman and Noyce 2013). The interaction between bicyclists and motorists is of particular interest because severe injuries and deaths often occur in collisions between a bicyclist and a motorized vehicle (Bíl, Bílová, and Müller 2010; Chaurand and Delhomme 2013; Matsui and Oikawa 2015). The riskiest situation for bicyclists is interacting with a motorized vehicle (Bíl et al. 2010; Kim et al. 2007; Räsänen and Summala 1998), particularly at an intersection (Carter et al. 2007; Reynolds et al. 2009; Wang and Nihan 2004). For example, (Kim et al. 2007) showed that more than 50% of crashes involving a bike and another vehicle (a car in 70% of the cases) occurred at an intersection.

Research on bicycle-overtaking manoeuvres has used the minimum lateral clearance between the bicyclist and the vehicle while the vehicle is passing as a surrogate measure for safety (Chapman and Noyce 2013; Love et al. 2012; Walker, Garrard, and Jowitt 2014). Previous research showed how lateral clearance is influenced by infrastructure design (e.g. presence of bike lanes) (Chapman and Noyce 2013; Frings, Parkin, and Ridley 2014), the behaviour of the bicyclist (e.g. speed, steering angle, speed variation control) (Chuang et al. 2013), and the bicyclist's appearance (such as outfit, gender and helmet wearing) (Chuang et al. 2013; Walker 2007; Walker et al. 2014). When motorists pass bicyclists, an event that happens frequently, motorists may be unaware of their small lateral distance from the bicyclists and encroach on their riding space; accordingly, this reduces the usable space available to bicyclists. A survey in Australia found that nearly 70% of 1830 male and female bicyclists reported that the most common form of drivers' harassment was driving too close (Heesch, Sahlqvist, and Garrard 2011).

6.3 Research questions

In order to explore the behaviour and the safety of bicyclists on roundabouts without bicycle facilities, the following research questions will be investigated in this study:

1. Does bicyclists' behaviour vary on roundabouts without bicycle facilities with regard to the diameter of the roundabout?
2. How does the presence of a vehicle affect the bicyclists' behaviour when riding on a roundabout without bicycle facilities?
3. Does bicyclists' behaviour vary on roundabouts without bicycle facilities with regard to helmet and reflecting devices use?

6.4 Methodology

6.4.1 Study locations

Four urban roundabouts without bicycle facilities in the region of Brussels (Belgium) were observed.

Since one of the aim of the study was to analyse the influence of roundabouts diameter on bicyclist behaviour, the four roundabouts were chosen in order to be similar from a geometric and design point of view except for the diameter. We therefore selected roundabouts with four legs that intersect at right angle (or similar), with absent or low longitudinal slope and with truck apron. As for the diameter, we chose two roundabouts with a diameter of 30 meters approximately and two roundabouts with a diameter of 20 meters approximately.

The first roundabout (Figure 6.1-a) is located in the municipality of Zaventem. It has a diameter of 32 meters. The second roundabout (Figure 6.1-b) is located in the municipality of Woluwe-Saint-Lambert and have a diameter of 22 meters. The third roundabout (Figure 6.1-c) is located in the municipality of Woluwe-Saint-Lambert and have a diameter of 30 meters. The fourth roundabout (Figure 6.1-d) is located in the municipality of Ixelles and have a diameter of 20 meters.

More details about the four roundabouts are presented in Table 6.1. Roundabout 1, 2 and 3 have a full raised truck apron, while roundabout 4 has a textured but not raised truck apron. Because of this truck apron was considered part of the circulatory roadway width for roundabout 4.

Figure 6.1– Observation sites: a) Roundabout 1 (Zaventem – D=32 meters); b) Roundabout 2 (Woluwe-Saint-Lambert – D=22 meters); c) Roundabout 3 (Tomberg – D=30 meters); d) Roundabout 4 (Ixelles – D=20 meters).

Table 6.1 – Characteristics of the four roundabouts analysed.

Characteristic	*Roundabout 1*	*Roundabout 2*	*Roundabout 3*	*Roundabout 4*
Number of legs	4	4	4	4
Diameter [m]	32.00	22.00	30.00	20.00
Circulatory roadway width [m]	6.00	6.10	7.40	6.20
Truck apron width [m]	2.21	1.89	2.06	2.13

6.4.2 Video data collection and analysis

At each site, two video cameras were mounted on different light poles to record oncoming bicyclists and vehicles on the roundabout. Five days of video, recorded in February, March and April 2019 from 7:00 a.m. to 7:00 p.m. were recorded for each roundabout (60 hours per roundabout).

The video footage is processed using T-Analyst, a semi-automated video analysis software developed at Lund University. The software is calibrated to transform the image coordinates of each individual pixel to road plane coordinates, which allows the accurate determination of the position of an object in the image and the calculation of its trajectory. This allows the calculation of road users' speeds and positions, distances and traffic conflict indicators in an accurate and objective way (Polders et al. 2015).

Some of the collected indicators (such as lateral position) require a high level of accuracy in the measurements (De Ceunynck et al. 2017). To ensure a sufficiently high accuracy, each video camera was used to record oncoming vehicles and bicyclists on a single quadrant. The video data analysis regards therefore two consecutive quadrants of each roundabout, i.e. half of each roundabout (Figure 6.2).

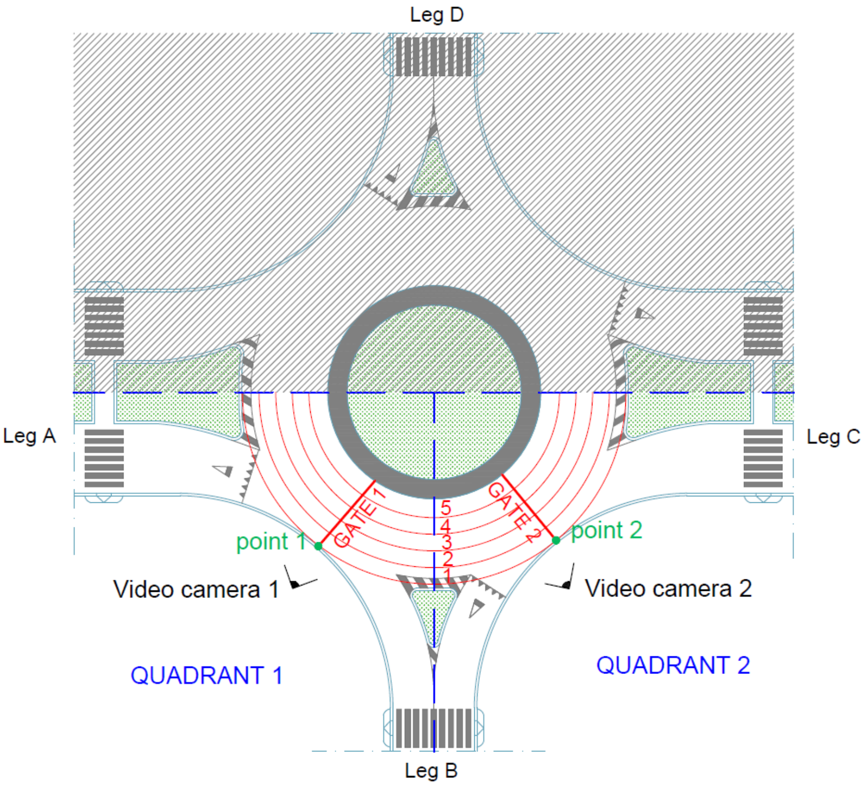

Figure 6.2 – Schematic representation of quadrants, video cameras position and gates.

All free-flow bicyclists and interactions between bicyclists and other vehicles that take place on the half roundabout during the observation period are selected for detailed analysis. Interactions between bicyclists and vehicles different from cars (i.e. buses, trucks, motorcycles, bicyclists) are really few in number. The analysis developed in this paper regards therefore only free-flow bicyclists and interactions between bicyclists and cars.

An interaction is defined as a situation in which two road users approach each other with such closeness in time and space that the presence of one road user can have an influence on the behaviour of the other (De Ceunynck et al. 2013). Four types of interactions are considered in order to take into account all the possible interactions between bicyclists and other road users:

1- following interactions;
2- overtaking interactions;
3- entering interactions - the road user on the entry leg goes first;
4- entering interactions - the road user on the entry leg doesn't go

first;

Following interactions are operationalised as each situation where a vehicle approaches a bicyclist or a bicyclist approaches a vehicle on the circulatory roadway to a distance of less than x meters, which equals the distance covered by the following vehicle or the following bicyclist in y seconds at a speed of z km/h. These situations can either be following situations where a vehicle is driving behind a bicyclist (named *following interaction – vehicle*) or following situations where a bicyclist is driving behind a road vehicle (named *following interaction – bicyclist*).

The speeds z, the temporal distances y and the resulting spatial distances x are equal to:

- x=21 meters for the roundabouts with bigger diameter (i.e. roundabout 1 and roundabout 3);
- x=14 meters for the roundabouts with smaller diameter (i.e. roundabout 2 and roundabout 4).

These values were deduced by the examination of a sample of following situations selected from the video observations of the four roundabouts analysed. First of all, the mean speeds in the middle of the quadrant of the following road users were calculated both for situations where a vehicle follows a bicyclist and for situations where a bicyclist follows a vehicle. Since the mean speed of bicyclists following vehicles was very similar to the mean speed of vehicles following bicyclists, it was considered the same mean speed both for bicyclists following vehicles and for vehicles following bicyclists (i.e. z=5.40 m/s=19.45 km/h for roundabouts with bigger diameter and z=4.63 m/s=16.7 km/h for roundabouts with smaller diameter). In order to identify the threshold temporal intervals y between interaction and no interaction situation, the speed variation $\Delta s = speed_0 - speed_1$ of the following user related to the temporal interval t_0-t_1 was calculated for each situation. t_0 is the instant where the following road user is at the minimum distance headway from the preceding user and t_1 is the instant where the following user reaches the point 0 where the preceding road user was at the instant t_0. Each situation where this speed variation Δs was a reduction major then 10% was considered as a following interaction because it can be assumed that the speed reduction of the following user is due to the presence of the preceding user. Other situations were considered as free-flow situations. The means of the temporal intervals for which the speed reductions were major than 10% are y = 3.8 s for the roundabouts with bigger diameter and y = 3.0 s for the roundabouts with smaller diameter. The resulting distances x (obtained by multiplying the temporal intervals y and the speed z) are x=20,53 meters for the roundabouts with bigger diameter and x=13.89 meters for the roundabouts with smaller diameter, which can be approximated respectively to x=21 meters and x=14 meters.

Overtaking interactions are operationalised as each situation where a vehicle overtakes a bicyclist or a bicyclist overtakes a vehicle on the circulatory roadway (named respectively *overtaking interaction – vehicle* and *overtaking interaction – bicyclist*).

Entering interactions – the road user on the entry leg goes first are operationalised as each situation where a road user (bicyclist or vehicle) enters the roundabout before another road user (vehicle or bicyclist) arriving from the quadrant on the left of the entry leg (named respectively *entering interactions – bicyclist enters first* and *entering interactions – vehicle enters first)*. These situations are considered interactions only when the road user on the entry leg can clearly see the other road user arriving on the circulatory roadway. This can be approximated to the situations where the road user is already on the quadrant on the left of the entry leg when the other road user is on the entry leg.

Entering interactions – the road user on the entry leg doesn't go first are operationalised as each situation where a road user (bicyclist or vehicle) enters the roundabout after another road user (vehicle or bicyclist) arriving from the quadrant on the left of the entry leg (named respectively *entering interactions – bicyclist doesn't enter first* and *entering interactions – vehicle doesn't enter first)*.

Free-flow bicyclists are defined as bicyclists who are not interacting with other vehicles. We consider therefore free flow bicyclists both bicyclists who ride the roundabout while no vehicles or other road users are on the whole roundabout and bicyclists who ride the roundabout when there are other road users on legs or parts of the roundabout which don't affect the trajectory of the free-flow bicyclist.

16 hours of video were analysed for each roundabout in order to identify free-flow bicyclists and bicyclists-vehicles interactions.

6.4.3 Collected variables about behaviour

For all events (both interactions and free-flow bicyclists), the following data related to bicyclists' behaviour are registered:

- Lateral position of the bicyclists in the middle of the quadrant, i.e. in the gates showed in ; for each roundabout we considered 5 virtual zones for lateral position, as shown in Figure 6.2. The five lateral positions are obtained dividing in 5 equal parts the circulatory roadway width.

- Normalized distance (N_d) from the edge of the circulatory roadway in the middle of the quadrant, i.e. in the gates showed in Figure 6.2; normalized distance is obtained dividing the distance between the external edge of the circulatory roadway (point 1and point 2 in Figure 6.2 respectively for gate 1 and gate 2) and the centroid of the bounding box around the bicyclist (which approximately corresponds with the contact point of the tyres on the road) by the circulatory roadway width. For each gate, normalized distance takes therefore values between 0 (at the external edge of the circulatory roadway) and 1 (at the internal edge of the circulatory roadway). There is therefore a direct correspondence between the five zones and the values of normalized distance: $0<N_d\leq0.2$ corresponds to zone 1; $0.2<N_d\leq0.4$ corresponds to zone 2; $0.4<N_d\leq0.6$ corresponds to zone 3; $0.6<N_d\leq0.8$ corresponds to zone 4; $0.8<N_d<1$ corresponds to zone 5.
- Riding speed of the bicyclist in the middle of the quadrant, i.e. in the gates showed in Figure 6.2. The riding speed is expressed in km/h.
- Helmet use.
- Reflecting devices use (e.g. yellow jacket).

For overtaking interactions, lateral overtaking proximity is additionally registered. For following interactions, distance headway is additionally registered. Distance headway and lateral overtaking proximity are expressed in meters.

6.5 Results and discussion

6.5.1 Analysis of free-flow bicyclists and bicyclists-vehicle interactions

The database obtained from the analysis of 16 hours of video for each roundabout consists of 974 records in total, 544 of which are bicycle-vehicle interactions and 430 are free-flow bicyclists. Table 3 shows the number of observed situations for roundabouts with bigger diameter (i.e. roundabouts 1 and 3) and for roundabouts with smaller diameter (i.e. roundabouts 2 and 4).

The following sections will analyse behavioural aspects of free-flow bicyclists and of bicyclists-vehicle interactions such as speed, lateral position, helmet use and occurrence of close interactions.

Table 6.2 – Number of observed situations for roundabouts with bigger diameter (roundabouts 1 and 3) and roundabouts with smaller diameter (roundabouts 2 and 4).

Condition	*Bigger diameter*	*Smaller diameter*	*Total*	
			Count	*Percent*
[1] Free-flow bicyclists (no interaction)	*188*	*242*	*430*	*44.15*
Interactions	*291*	*258*	*544*	*55.85*
[2] Following interactions – vehicle follows bicyclist	80	84	164	16.84
[3] Following interactions – bicyclist follows vehicle	53	45	98	10.06
[4] Overtaking interactions – vehicle overtakes bicyclist	10	2	12	1.23
[5] Overtaking interactions – bicyclist overtakes vehicle	5	3	8	0.82
[6] Entering interactions - vehicle enters first	11	13	24	2.46
[7] Entering interactions - bicyclist enters first	33	23	56	5.75
[8] Entering interactions - vehicle doesn't enter first	50	41	91	9.34
[9] Entering interactions - bicyclist doesn't enter first	44	47	91	9.34
Total	*479*	*500*	*979*	*100.00*

6.5.1.1 Behavioural aspects of free-flow bicyclists

To answer the question of whether free-flow bicyclists' behaviour varies on roundabouts without bicycle facilities with regard to the diameter of the roundabout and with regard to helmet and reflective devices use, two univariate analyses of variance (ANOVA) were conducted considering only free-flow bicyclists. The sample considered for these analyses is therefore 430 free-flow bicyclists. The dependent variables are the bicyclists' riding speed for the first ANOVA and the lateral position in the middle of the quadrant for the second one. Riding speed in the middle of the quadrant is expressed in km/h and is subdivided in four ranges (i.e. ≤15 km/h, 15-20 km/h, 20-25 km/h, >25 km/h). Lateral position in the middle of the quadrant is expressed as normalized distance from the edge of the circulatory roadway, so it can range from 0 to 1. The independent variables are for both ANOVAs the diameter of the roundabout (bigger diameter or smaller diameter), the helmet (helmet or no helmet) and the reflective devices (reflective devices or no reflective devices). For all analyses the maximum p-value was set at 0.05 to determine statistical significance.

The analysis of the influence of helmet and reflective devices use on bicyclists' behaviour was carried out taking into account respectively the variables use of helmet and use of reflective devices; other variables which could affect the observed speeds and lateral positions, such as gender, age, travel purpose and type of bicycle, were not considered for this analysis because it was not easy to deduce them univocally from the video recordings.

Table 6.3Table 6.3 – Mean values of free-flow bicyclists' speed and normalized distance (lateral position). shows the mean values of free-flow bicyclists' speed and lateral position. Table 6.4 shows the results of the ANOVA tests for free-flow bicyclists' speed and lateral position.

Table 6.3 – Mean values of free-flow bicyclists' speed and normalized distance (lateral position).

	Bigger diameter	*Smaller diameter*
Overall mean speed (v_{mean})		
[1] Free-flow bicyclists (no interaction)	21.16 km/h	17.55 km/h
Overall mean normalized distance (N_{d_mean})		
[1] Free-flow bicyclists (no interaction)	0.63 (zone 4)	0.55 (zone 3)
	All roundabouts	
Overall mean speed (v_{mean})		
Helmet	19.78 km/h	
No helmet	18.13 km/h	
Reflective devices	19.78 km/h	
No reflective devices	18.73 km/h	
Overall mean normalized distance (N_{d_mean})		
Helmet	0.59	
No helmet	0.56	
Reflective devices	0.62	
No reflective devices	0.57	

The ANOVA test for speed (Table 6.4) shows that speed is significantly different between the two different diameters ($p<0.001$). Looking at the mean values of speed (Table 6.3) we can see that free-flow bicyclists ride significantly faster on roundabouts with bigger diameter (v_{mean}=21.16 km/h) compared to roundabouts with smaller diameter (v_{mean}=17.55 km/h). This suggests that the effect of centrifugal forces, which are higher on roundabouts with smaller diameter compared to roundabouts with bigger diameter, lead bicyclists to ride slower on roundabouts with smaller diameter and faster on roundabouts with bigger diameter. -a shows the percentage of free-flow bicyclists for the four ranges of speed differentiated for roundabouts with bigger and smaller diameter. It can be seen that free-flow bicyclists ride significantly faster on roundabouts with bigger diameter: more than 22% of free-flow bicyclists has a speed higher than 25 km/h on roundabouts with bigger diameter, while only 2.5% of free-flow bicyclists has the same speed on roundabouts with smaller diameter. By contrast, more than 26% of free-flow bicyclists has a speed lower than 15 km/h on roundabouts with smaller diameter, while only 9% of free-flow bicyclists has the same speed on roundabouts with bigger diameter. -a also shows that the majority (45.9%) of free-flow bicyclists on roundabouts with smaller diameter has a speed between 15 and 20 km/h and more than 72% of them rides with a speed lower than 20 km/h. On the other hand, more than 56% of free-flow bicyclists rides with a speed higher than 20 km/h on roundabouts with bigger diameter.

Table 6.4 - ANOVA tests for free-flow bicyclists' speed and normalized distance (lateral position).

	Mean square	F	p-value
ANOVA dependent variable: speed range			
Diameter	20.929	31.124	<0.001
Helmet	4.174	6.225	0.013
Reflecting devices	3.240	4.832	0.028
ANOVA dependent variable: normalized distance			
Diameter	0.438	9.584	0.002
Helmet	0.008	0.177	0.674
Reflecting devices	0.169	3.700	0.055

The ANOVA test for normalized distance (Table 6.4) shows that normalized distance is also significantly different between the two different diameters ($p=0.002<0.05$). Looking at the mean values of normalized distance (Table 6.3Table 6.3 – Mean values of free-flow bicyclists' speed and normalized distance (lateral position).) we can see that free-flow bicyclists ride closer to the central island on roundabouts with bigger diameter ($N_{d\_mean}=0.63$, corresponding to zone 4) compared to roundabouts with smaller diameter ($N_{d\_mean}=0.55$, corresponding to zone 3). Figure 6.3-b shows the percentage of free-flow bicyclists for the five zones of lateral position differentiated for roundabouts with bigger and smaller diameter. It can be seen that more than 45% of free-flow bicyclists rides on zone 4 for roundabouts with bigger diameter, while only 23% of free-flow bicyclists ride on the same zone for roundabouts with smaller diameter. Conversely, more than 45% of free-flow bicyclists rides on zone 3 for roundabouts with smaller diameter, while only 25% of free-flow bicyclist rides in the same zone for roundabouts with bigger diameter. We can therefore conclude that bicyclists ride closer to the centre island on larger roundabouts and the difference is mostly found in zones 3 and 4; the shares of bicyclists in zones 1, 2 and 5 do not differ much between both locations. -b shows that free-flow bicyclists are not inclined to assume the most constraining lateral position, i.e. the one close to the external edge of the circulatory roadway (zone 1) both for smaller and bigger diameter. At the same time really few percentages of free-flow bicyclists choose the more internal lateral position (zone 5) both for smaller and bigger diameter. This is probably due to the fact that bicyclists don't feel safe and confident riding too close to the central island. The majority of free-flow bicyclists chooses zone 3 for roundabouts with smaller diameter (40.1%) and zone 4 for roundabouts with bigger diameter (45.7%). We can therefore conclude that in general free-flow bicyclists tend to choose lateral positions less constraining in terms of resistances (i.e. lateral positions far from the external edge of the circulatory roadway). This is more evident on roundabouts with bigger diameter, probably because bigger radii of trajectories favour the predisposition to ride close to the central island.

The ANOVA test for speed (Table 6.4) also shows that there is a significant relationship between speed and helmet ($p=0.013<0.05$). The mean values of speed related to bicyclists using or not helmet shows that free-flow bicyclists using helmet (v_{mean}=19.78 km/h) ride faster than free-flow bicyclists without helmet (v_{mean}=18.13 km/h). Among studies that have explicitly investigated effects of helmet use on behaviour, most studies do not support the hypothesis that helmet use contributes to riskier cycling behaviour. Fyhri and Phillips (2013) and Phillips et al. (2011) show that cyclists who normally are not using bicycle helmets, do not cycle faster when cycling with a helmet in real traffic. Messiah et al. (2012) found that male cyclists who had not regularly been using helmets, cycled faster when given helmets. However, no such effect was found among female cyclists. Lardelli-Claret et al. (2003) didn't find a relationship between helmet use and cycling at high speed. The results found in this study could mean that bicyclists who are using helmet are inclined to ride roundabouts at higher speed, but considering the results of previous studies a more appropriate interpretation could be that cyclists who know that they are fast take extra protective measures, rather than that the protective measure has an effect by itself. Our results could therefore mean that faster cyclists wear a helmet because of the fact that they know they are riding faster. Of course it has to be taken into account that wearers and non-wearers of helmets differ also with respect to gender, age, travel purpose, type of bicycle, all elements that also clearly could influence the observed speeds.

Figure 6.4-b shows the percentage of free-flow bicyclists for the four ranges of speed differentiated for bicyclists with and without helmet. It can be seen that free-flow bicyclists with helmet ride faster than free-flow bicyclists without helmet: more than 15% of free-flow bicyclists with helmet has a speed higher than 25 km/h, while only 4% of free-flow bicyclists without helmet has the same speed. By contrast, 25% of free-flow bicyclists without helmet has a speed lower than 15 km/h, while only 15% of free-flow bicyclists with helmet has the same speed.

The ANOVA test for normalized distance (Table 6.4) shows that normalized distance is not significantly different between free-flow bicyclists using or not helmet ($p=0.674>0.05$). This suggests that the fact that bicyclists use helmet affect their speed but don't affect their lateral position.

The ANOVA test for speed (Table 6.4) finally shows that there is a significant relationship between speed and reflective devices ($p=0.028<0.05$). The mean values of speed related to bicyclists using or not reflective devices shows that free-flow bicyclists using reflective devices (v_{mean}=19.78 km/h) ride faster than free-flow bicyclists who are not using reflective devices (v_{mean}=18.73 km/h). Although studies that have explicitly investigated effects of reflective devices on bicyclists are principally related to the risk of crash related injury (Bíl et al. 2010; Hagel et al. 2007, 2014; McGuire and Smith 2000), similar considerations as those made for helmet can be done. A possible explanation for these results could therefore be that bicyclists who know that they are fast take extra protective measures, rather than that the protective measure has an effect by itself. We can hypothesize that faster cyclists wear reflective devices because of the fact that they know they are riding faster. Also in this case it has to be taken into account that wearers and non-wearers of reflective devices differ also with respect to gender, age, travel purpose, type of bicycle, all elements that also clearly could influence the observed speeds.

Figure 6.4-b shows the percentage of free-flow bicyclists for the four ranges of speed differentiated for bicyclists with and without reflective devices. It can be seen that free-flow bicyclists without reflective devices ride slower than free-flow bicyclists with reflective devices: more than 23% of free-flow bicyclists without reflective devices has a speed lower than 15 km/h, while only 12% of free-flow bicyclists with reflective devices has the same speed. Moreover, more than 45% of bicyclists with reflective devices has speed higher than 20 km/h, while less than 36% of free-flow bicyclists without reflective devices has the same speed.

The ANOVA test for normalized distance (Table 6.4) shows that normalized distance is not significantly different between free-flow bicyclists using or not reflective devices (p=0.055>0.05). This suggests that the fact that bicyclists use reflective devices affect their speed and is likely to affect their lateral position too.

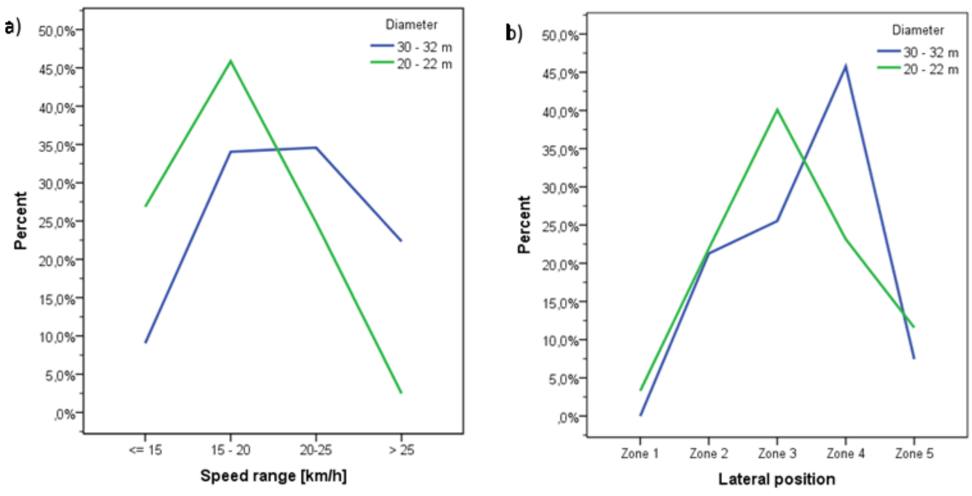

Figure 6.3 – a) Speed range of free-flow bicyclists for roundabouts with bigger diameter (30-32 m) and smaller diameter (20-22 m); b) Lateral position of free-flow bicyclists for roundabouts with bigger diameter (30-32 m) and smaller diameter (20-22 m).

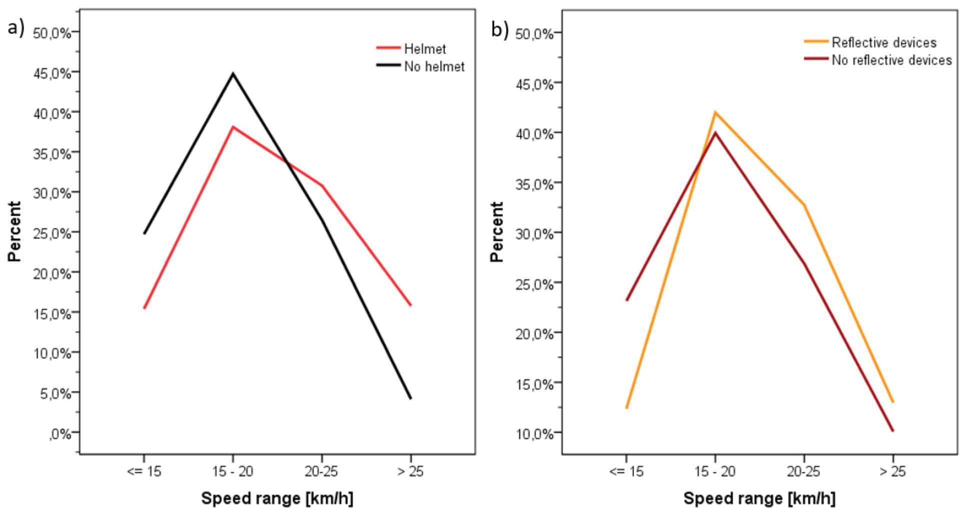

Figure 6.4 – a) Speed range of free-flow bicyclists with and without reflecting devices; b) Speed range of free-flow bicyclists with and without helmet.

6.5.1.2 Behavioural aspects of bicyclists-vehicle interactions

To answer the question of whether bicyclists' behaviour vary on roundabouts without bicycle facilities with regard to the diameter of the roundabout and of how the presence of a vehicle affect bicyclists' behaviour when riding on a roundabout without bicycle facilities, univariate analyses of variance (ANOVA) are conducted considering both for free-flow bicyclists and bicyclists-vehicle interactions. Conditions n. [4], [5], [6], [7] (i.e. *overtaking interactions – vehicle, overtaking interactions- bicyclists, entering interactions - vehicle enters first* and *entering interactions- bicyclist enters first*) are not considered for these analysis because they are less than 6% of the total sample (see Table 6.2). The total sample considered for these ANOVA analyses is therefore 874 situations, 444 of which are bicycle-vehicle interactions (conditions [2], [3], [6], [7] in Table 6.2) and 430 are free-flow bicyclists (condition [1] in Table 6.2).

The dependent variables are the bicyclists' riding speed for the first ANOVA and the lateral position in the middle of the quadrant for the second one. Riding speed in the middle of the quadrant is expressed in km/h and is subdivided in four ranges (i.e. *≤15 km/h*, *15-20 km/h*, *20-25 km/h*, *>25 km/h*). Lateral position in the middle of the quadrant is expressed as normalized distance from the edge of the circulatory roadway. The independent variables are for both ANOVAs the diameter of the roundabout (*bigger diameter* or *smaller diameter*) and the condition (*[1] Free-flow bicyclists (no interaction)*, *[2] Following interactions - vehicle*, *[3] Following interactions - bicyclist*, *[6] Entering interactions - vehicle doesn't enter first*, *[7] Entering interactions - bicyclist doesn't enter first*). For all analyses the p-value was set at 0.05 to determine statistical significance.

Table 6.5 shows the mean values of bicyclists' speed and lateral position. Table 6.6 shows the results of the ANOVA tests for bicyclists' speed and lateral position.

The ANOVA test for speed (Table 6.6) shows that speed is significantly different between the two different diameters ($p<0.001$). Looking at the mean values of speed (Table 6.5) and at Figure 6.5-a we can see that bicyclists ride significantly faster on roundabouts with bigger diameter compared to roundabouts with smaller diameter for all the conditions analysed. This means that, regardless of the type of condition (free-flow or different interactions), bicyclists always ride faster on roundabouts with bigger diameter and slower on roundabouts with small diameter. This supports what we already observed in paragraph 5.1., i.e. that the effect of centrifugal forces, which are major on roundabouts with smaller diameter and minor on roundabouts with bigger diameter, lead bicyclists to ride slower on roundabouts with smaller diameter and faster on roundabouts with bigger diameter.

The ANOVA test for normalized distance (Table 6.6) shows that normalized distance is significantly different between the two different diameters ($p=0.002<0.05$). The mean values of normalized distance (Table 6.5) and Figure 6.5-a shows that bicyclists ride closer to the central island on roundabouts with bigger diameter ($N_{d\_mean}=0.63$, corresponding to zone 4) compared to roundabouts with smaller diameter ($N_{d\_mean}=0.55$, corresponding to zone 3) for all the conditions analysed. Regardless of the type of condition (free-flow or different interactions), bicyclists therefore ride closer to the central island on roundabouts with bigger diameter. We can therefore conclude that in general bicyclists tend to choose lateral positions less constraining in terms of resistances (i.e. lateral positions far from the external edge of the circulatory roadway). This is more evident on roundabouts with bigger diameter, probably because bigger radii of trajectories favour the predisposition to ride close to the central island.

Table 6.5 - Mean values of bicyclists' speed and normalized distance (lateral position) for all conditions.

	Bigger diameter	*Smaller diameter*
Overall mean speed (v_{mean})		
[1] Free-flow bicyclists (no interaction)	21.16	17.55
[2] Following interactions - vehicle	18.71	16.40
[3] Following interactions - bicyclist	20.19	16.94
[6] Entering interactions - vehicle doesn't enter first	20.84	16.93
[7] Entering interactions - bicyclist doesn't enter first	15.82	13.07
Overall mean normalized distance (N_{d_mean})		
[1] Free-flow bicyclists (no interaction)	0.63	0.55
[2] Following interactions - vehicle	0.55	0.51
[3] Following interactions - bicyclist	0.59	0.55
[6] Entering interactions - vehicle doesn't enter first	0.63	0.55
[7] Entering interactions - bicyclist doesn't enter first	0.56	0.54

The ANOVA tests for speed and for lateral position (Table 6.6) show that speed and lateral position are also significantly different among the different conditions ($p<0.001$ for speed and $p=0.018<0.05$ for lateral position). Figure 6.5-a and b) shows the mean values of speed of bicyclists for each condition differentiated for bigger and smaller diameter. By comparing speed and lateral position of free-flow bicyclists with speed and lateral position of each type of interaction it is possible to understand how the different type of interactions affect the behaviour of bicyclists. The interactions affecting more bicyclists behaviour both in terms of speed and lateral position are *following interactions – vehicle* (condition [2]) and *entering interactions – bicyclist doesn't enter first* (condition [7]).

E*ntering interaction – bicyclist doesn't enter first* (condition [7]) is of course strongly conditioning in terms of speed because the bicyclists is entering the roundabout and his speed is therefore definitely lower than the free-flow case. Table 6.5 and Figure 6.5-a show that for both bigger and smaller diameters the mean speed of interactions [7] (15.82 km/h and 13.07 km/h respectively) is lower than the mean speed of free-flow bicyclists (21.16 km/h and 17.55 km/h respectively). Table 6.5 and Figure 6.5-b show that for both bigger and smaller diameters also the mean normalized distance of interactions [7] (0.56 and 0.54 respectively) is lower than the mean normalized distance of free-flow bicyclists (0.63 and 0.55 respectively). This suggests that bicyclists entering the roundabout are naturally more inclined to ride close to the external edge of the circulatory roadway. It is however essential to note that the lower values of speed and normalized distance are due to the type of manoeuvre (entering manoeuvre) rather than to the vehicle's influence.

Following interaction – vehicle (condition [2]) definitely seems to be the type of interaction mostly affecting the behaviour of bicyclists from a psychological point of view. During this type of interaction, a vehicle is driving behind a bicyclist on the circulatory roadway. The bicyclist is therefore riding on the circulatory roadway and is not doing manoeuvres which could affect his speed or his lateral position. The only element that can affect his behaviour is the presence of the following vehicle. Table 6.5 and Figure 6.5-b show that for both bigger and smaller diameters the mean normalized distance of interactions [2] (0.55 and 0.51 respectively) is lower than the mean normalized distance of free-flow bicyclists (0.63 and 0.55 respectively). Figure 6.6 shows the percentage of bicyclists for condition [2] (*following interactions – vehicle*) for the five zones of lateral position differentiated for roundabouts with bigger and smaller diameter. From the comparison of Figure 6.6 and Figure 6.3-b it can be seen that for bigger diameter the majority of free-flow bicyclists rides on zone 4 (45.7%) while the majority of bicyclists who are followed by a vehicle rides on zone 3 (42.5%). In the same way, for smaller diameter the majority of free-flow bicyclists rides on zone 3 (40.1%) while the majority of bicyclists who are followed by a vehicle is distributed on zone 2 and zone 3 (34.5% and 35.7% respectively). This suggests that bicyclists are strongly conditioned by the presence of the following vehicle in roundabouts and are therefore inclined to ride closer to the external edge of the circulatory roadway, both for roundabouts with bigger and smaller diameter. This is probably due to the fact that bicyclists don't feel confident and safe while followed by a vehicle and tend therefore to assume a more external position in order to favour the overtaking. Since bicyclists tend to assume a more external lateral position, the resulting trajectories on the circulatory roadway are likely longer and have a higher curvature compared to the trajectories of free-flow bicyclists. This obviously results in a reduction of speed, which is confirmed by Table 6.5 and Figure 6.5-a. We can indeed observe that for both bigger and smaller diameters the mean speed of interactions [2] (18.71 km/h and 16.40 km/h respectively) is lower than the mean speed of free-flow bicyclists (21.16 km/h and 17.55 km/h respectively). It seems that the reduction of speed and normalized distance associated to interactions [2] is higher for roundabouts with bigger diameter rather than for roundabouts with small diameter. Mean speed difference between free-flow bicyclists and interactions [2] is indeed 2.41 km/h for bigger diameter and 1.15 km/h for smaller diameter. In the same way, normalized distance difference between free-flow bicyclists and interactions [2] is 0.08 for bigger diameter (corresponding to the switch from zone 4 to zone 3) and 0.04 for smaller diameter (corresponding to the shift to the most external part of zone 3). This suggests that bicyclists feel more confident on roundabouts with small diameter and are therefore able to deal better with the presence of a following vehicle.

Table 6.6 - ANOVA tests for bicyclists' speed and normalized distance (lateral position) for all conditions.

	Mean square	F	p-value
ANOVA dependent variable: speed range			
Diameter	54.179	88.011	<0.001
Condition	15.814	25.690	<0.001
ANOVA dependent variable: normalized distance			
Diameter	0.428	9.349	0.002
Condition	0.137	3.002	0.018

Following interactions – bicyclist (condition [3]) and *Entering interactions - vehicle doesn't enter first* (condition [6]) do not seem to affect bicyclists' speed and lateral position. Mean speed of interactions [3] and [6] are indeed very similar to mean speed of free-flow bicyclists both for roundabouts with bigger and smaller diameter (see Table 6.5 and Figure 6.5-a. At the same time, mean normalized distance of interactions [3] and [6] are very similar to mean normalized distance of free-flow bicyclists both for roundabouts with bigger and smaller diameter (see Table 6.5 and Figure 6.5-b. The presence of a vehicle preceding the bicyclist on the circulatory roadway (interaction [3]) or the presence of a vehicle entering the roundabout after the bicyclist (interaction [6]) does not seem to affect bicyclists' behaviour.

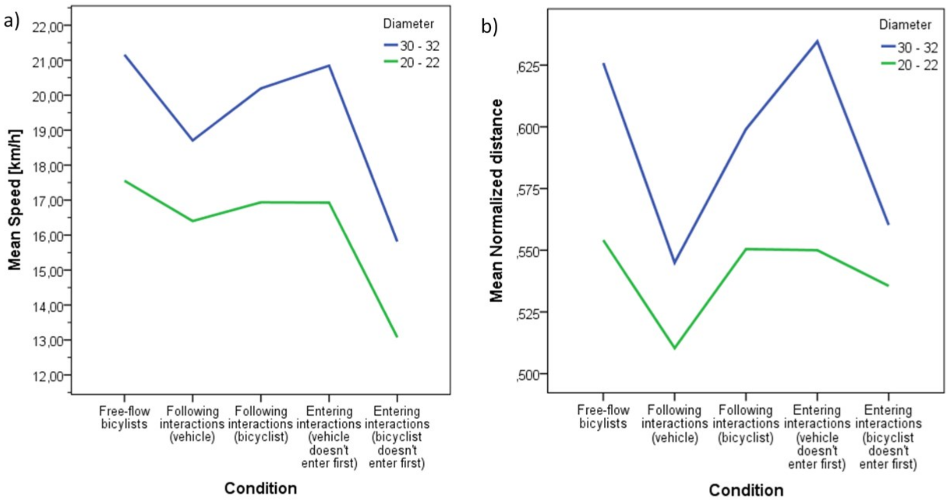

Figure 6.5– a) Mean speed of bicyclists for each condition for roundabouts with bigger diameter (30-32 m) and smaller diameter (20-22 m); b) Mean normalized distance for each condition for roundabouts with bigger diameter (30-32 m) and smaller diameter (20-22 m).

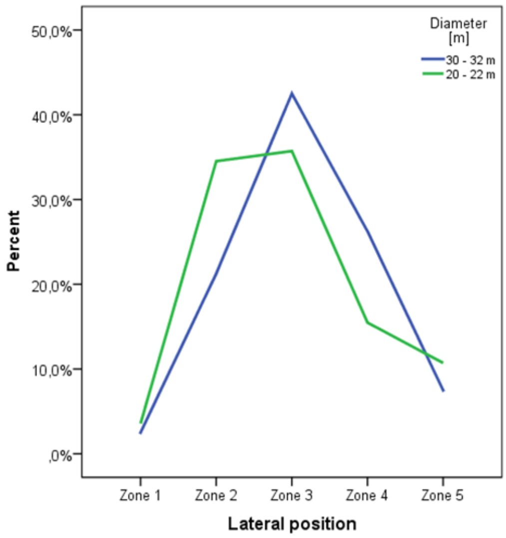

Figure 6.6– Lateral position of bicyclists for interactions [2] (*following interactions – vehicle*) for roundabouts with bigger diameter (30-32 m) and smaller diameter (20-22 m).

6.6 Conclusions

Observations at four roundabouts with mixed traffic revealed that free-flow bicyclists ride significantly faster on roundabouts with bigger diameter compared to roundabouts with smaller diameter. It was also observed that free-flow bicyclists tend to choose lateral positions less constraining in terms of resistances (i.e. lateral positions far from the external edge of the circulatory roadway). This is more evident on roundabouts with bigger diameter, probably because bigger radii of trajectories favour the predisposition to ride close to the central island. The analysis of bicyclists' behaviour with regard to the use of helmet that free-flow bicyclists using helmet ride faster than free-flow bicyclists without helmet. This could be due to the fact that cyclists who know that they are fast take extra protective measures, rather than that the protective measure has an effect by itself. The same consideration is valid for bicyclists using reflective devices, who were found to ride faster than bicyclists not using reflective devices.

The analysis of speed and lateral positions for different conditions showed that regardless of the type of condition (free-flow or different interactions), bicyclists always ride faster and closer to the central island on roundabouts with bigger diameter. By comparing speed and lateral position of free-flow bicyclists with speed and lateral position of each type of interaction it is possible to understand how the different type of interactions affect the behaviour of bicyclists. *Following interaction – vehicle* (condition [2]) seems to be the type of interaction mostly affecting the behaviour of bicyclists from a psychological point of view. For both bigger and smaller diameters, the mean normalized distance of interactions [2] is lower than the mean normalized distance of free-flow bicyclists. This suggests that bicyclists are strongly conditioned by the presence of the following vehicle in roundabouts and are therefore inclined to ride closer to the external edge of the circulatory roadway, both for roundabouts with bigger and smaller diameter. This is probably due to the fact that bicyclists don't feel confident and safe while followed by a vehicle and tend therefore to assume a more external position in order to favour the overtaking. Since bicyclists tend to assume a more external lateral position, the resulting trajectories on the circulatory roadway are likely longer and have a higher curvature compared to the trajectories of free-flow bicyclists. This obviously results in a reduction of speed, which is confirmed by the values of speed observed.

6.7 References

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7. ELDERLY PERCEPTION OF CRITICAL ISSUES OF PEDESTRIAN PATHS

This chapter intends to contribute for a better understanding of elderly pedestrian perception of pedestrian paths. The aim is to identify and characterize how old pedestrians perceive pedestrian paths with respect to their age related declines in perceptual and physical abilities and with respect to their experiences as road users. A survey was developed in order to collect elderly pedestrians' opinions. K-Means cluster analysis and hierarchical cluster analysis were used in order to understand how analyze the key components that influence the elderly pedestrians' perception of pedestrian paths and to identify how these perceptions change for different pedestrian "profiles" of elderly pedestrians based on human factors.

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7.1 Introduction

Deaths and injuries resulting from road traffic crashes is a serious problem globally and current trends suggest that this will continue to be the case in the foreseeable future [1]. According to the World Health Organization, the number of annual road traffic deaths reached 1.35 million in 2018, which is considered to be the eighth leading cause of death globally [2].

Of the total 1.35 million people dying in road traffic crashes annually, at least 30% are in urban areas [2]. Pedestrians are considered the most fragile road users in the transport system. They are at maximum risk compared to any other road users because of their fragility, slow pace, and their absence of protection [3]. In Europe, the safety of a pedestrian has been problematic for a long time. The actions taken to reduce pedestrian crashes have been much less notable compared to those for the total traffic accidents, although the total number of fatalities has decreased significantly during the period 2006–2016. In the European Union, a total of 5320 pedestrians were killed in road accidents in 2016, 21% of all road fatalities [4].

The reality of an aging population, particularly in ‘‘economically developed” countries, has made the everyday mobility of seniors an issue of growing interest. In a context where an increasing number of people globally are dependent on cars, efforts to encourage walking - both utilitarian and leisurely - has become a public health priority [13]. However, public transportation and walking environments are not always well-adapted to accommodate the elderly. In order for walking to become an attractive, efficient, and safe mode of transportation for the elderly, the way public spaces are designed must be rethought/reconsidered in order to accommodate to their needs and preferences.

Age related declines in perceptual, cognitive, and physical abilities have been shown to result in non-optimal street-crossing decisions and behaviors [6, 7, 8] and may contribute to the high rate of fatal or serious-injury crashes found for old pedestrians [9]. Because of age-related perceptual, cognitive, and motor limitations, and in line with [10] as well as [11], old pedestrians are expected to experience more difficulty than young pedestrians.

Considering the above facts, it is important to identify and characterize how old pedestrians perceive pedestrian paths with respect to their age related declines in perceptual and physical abilities and with respect to their experiences as road users. The final aim of this study is first of all to understand which critical issues old pedestrians found in the pedestrian paths they usually walk. Moreover, this study seeks to analyze how old pedestrians’ age related declines in perceptual and physical abilities (vision, hearing and mobility problems) and experiences as road user (no driving license, no still driving, accidents driving, accident pedestrian) can affect their opinion on the critical issues of pedestrian paths. This is important to determine interventions and could support traffic engineers, planners, and decision-makers to consider the contributing factors in engineering countermeasures.

7.2 An overview of the literature

Walking is particularly important for the elderly, who are less likely than younger adults and children to participate in more vigorous forms of physical activity, more likely to experience social isolation and less likely to drive a car. Walking is also highly valued by seniors for a range of reasons, including improved health, wellbeing, independence, personal mobility and social connectedness. Moreover, walking is critical to allow older people to conduct day-to-day activities, such as shopping, attending meeting places (sporting clubs, libraries and community centers) and visiting essential services like doctors and hospitals [12]. In addition, reference [13] shows that in Italy 33% of grandparents take care of grandsons every day. This makes increasingly important to create safe walking opportunities around schools, as the two most vulnerable road user types walks together [14]. Walking can also reduce transport-related costs, including lower personal expenditure on fuel and vehicle maintenance. These aspects can be critical for older adults, who generally have lower annual incomes and for whom transport costs may represent a larger component of their expenses. The combination of these factors can result in transport disadvantage and social exclusion, which has been identified as a significant problem facing older adults [15].

It is well understood that walking has significant physical health benefits for older people, including reduced risk of many chronic diseases such as obesity, heart disease and diabetes [12, 15]. A well-established finding in the literature is a link between physical activity and decreased risk of many chronic diseases [16], including cardiovascular disease in people of all ages [17]. When analyzing the vulnerability of older pedestrians, it is important to consider the impact of physiological and cognitive changes that occur as people age. The World Health Organization in its 2013 report "Pedestrian Safety - A Road Safety Manual for Decision Makers and Practitioners" states that the combination of the following factors increases the vulnerability of older pedestrians: deterioration in visual acuity results in older pedestrians accepting significantly smaller gaps in traffic than required when crossing roads; cognitive decline results in reduced ability to make safe judgments about walking speed and traffic gaps; reduced mobility results in an inability to react quickly and avoid crashes; frailty and existing health conditions can result in greater injury severity when a crash does occur; slower walking speeds can result in older pedestrians being stranded in the middle of the road when attempting to cross at signalized crossings.

Ageing results in gradual deterioration of agility (walking speed and balance), sensory perception (vision and hearing) and cognitive skills (attention and information processing speed). Older pedestrians can thus experience problems in situations that demand efficient cognitive processing, fast responses and quick actions [18].

Age-related changes reduce people’s ability to undertake the many cognitive tasks required when crossing roads, such as finding a place to cross a road, looking for traffic, perceiving traffic, judging vehicle speeds and available gaps, deciding when to cross and then crossing the road. Older pedestrians are over-represented in crashes at complex intersections (particularly those with two-way traffic and/or multiple lanes) and when traffic volumes and speeds are high.

Outdoor walking, as a type of physical activity, takes place in outdoor spaces. It has well-known benefits for health in later life and older adults are recommended to take outdoor walks [19-21].

Evidence indicates that neighborhood safety, pedestrian infrastructure and aesthetics are important for supporting and encouraging outdoor walking [22-26] because pedestrians move slowly in outdoor spaces thus affording the ability to notice route characteristics [27].

These built environment attributes seem especially important for older adults' outdoor walking [19, 28, 29, 30]. For example, older adults may avoid walking to available attractive destinations located in walking distances due to high risk of accident [29]. Evidence has shown that for older adults' outdoor walking, maximizing the neighborhood aesthetics or quality of pedestrian infrastructure is more important than minimizing the distance to a destination [29].

Reference [31] examines inequalities in perceived built environment attributes (i.e., safety, pedestrian infrastructure and aesthetics) and their possible influences on disparities in older adults' outdoor walking levels in low- and high-deprivation areas of Birmingham, United Kingdom. It applied a mixed-method approach, included 173 participants (65 years and over), used GPS technology to measure outdoor walking levels, used questionnaires and conducted walking interviews to collect data on perceived neighborhood built environment attributes. The results show inequalities in perceived neighborhood safety, pedestrian infrastructure and aesthetics in high- versus low-deprivation areas and demonstrate that they may influence disparities in participants' outdoor walking levels. Improvements of perceived neighborhood safety, pedestrian infrastructure and aesthetic in high-deprivation areas are encouraged. Most participants, particularly in high-deprivation areas, also talked about perceived uneven pavements, broken slabs, presence of potholes, cracks and obstacles (e.g., knocked down bollards) in pavements.

Reference [32] uses an experimental study design with computer-simulated living environments to investigate the effect of micro-scale environmental factors (parking spaces and green verges with trees) on older people's perceptions of both motivational antecedents (dependent variables). Seventy-four consecutively recruited older people were randomly assigned watching one of two scenarios (independent variable) on a computer screen. The scenarios simulated a stroll on a sidewalk, as it is 'typical' for a German city. In version "A" the subjects take a fictive walk on a sidewalk where a number of cars are parked partially on it. In version “B”, cars are in parking spaces separated from the sidewalk by grass verges and trees. Subjects assessed their impressions of both dependent variables. A multivariate analysis of covariance showed that subjects’ ratings on perceived traffic safety and pedestrian friendliness were higher for version “B” compared to version “A”. The study suggests that elements of the built environment might affect motivational antecedents of older people’s walking behavior.

Many researches examine the perception of elderly pedestrians about the quality and risks of the elements that characterize pedestrian routes (e. g., sidewalks and pedestrian crossings) in various investigation contexts. In particular, Reference [33] examines the case of road crossings in the context of Montréal, Québec, Canada. The analyze are based on observations and questionnaires in order to bring to light a better understanding of the relationship between the crossing behaviors, characteristics and perceptions of the elderly. Five profiles of elderly people in both urban and suburban environments were established. A sample of 181 elderly pedestrians (65–93 years of age) were surveyed using a questionnaire. In addition to close-ended questions, respondents were asked to evaluate 17 environmental ambiance and risk behaviors according to various scales. Using principal component analysis (PCA) and hierarchical cluster analysis (HCA), the data was grouped into 6 categories that define and distinguish 7 profiles of elderly people. These profiles were explored according to the socioeconomic status and crossing behaviors of respondents. The probabilities of adopting different crossing behaviors were tested by employing logistic regression models. The results reveal greater variability in the perceptions of the elderly in terms of risk related to crossing behaviors and type of signalization at intersections.

In Reference [34], both common and diverse contributory factors to elderly pedestrian injuries are investigated, by segmenting the elderly into the younger-old (between 65 and 74 years) and older-old (over 75 years). By employing single and interaction binary logit models, the study identified common risk factors for both elderly groups, as well as those that are particularly hazardous to the older-old. It was found that older age was the most critical risk factor leading to severe injury. A set of common contributory factors for both elderly groups was identified, including near overpass crossing, roadside, drunk, and truck. On the other hand, uphill, downhill, nighttime, and sidewalk were found to be a much higher risk to the older-olds.

Finally, a 2012 Belgian research [35] is particularly interesting for the purposes of this study. Reference [35] sought to uncover the perceived environmental influences by elderly Flemish pedestrians. To get detailed and context-sensitive environmental information, it used walk-along interviews. Almost all participants mentioned the importance of the presence and quality of sidewalks. In case of absence of a sidewalk, characteristics of the streets and their shoulders were discussed. Streets with busy traffic or an uneven surface were perceived as less attractive to walk on. When a shoulder was present to walk on, uneven or muddy surfaces were disliked as well. When sidewalks were present, almost all participants mentioned issues related to the sidewalks' quality. They said they liked sidewalks that were well-maintained and even, and judged as hazardous and thus disliked cracked or uneven sidewalks, or sidewalks that had puddles, ice, snow, mud, or leaves. They also viewed sidewalks with steep cross-slopes as hazardous of becoming slippery during snowy and icy conditions. Adequate street lighting was mentioned as important for identifying fall hazards during walks after dark. Sidewalk width was also discussed. Participants preferred sidewalks wide enough for people to walk next to each other, to easily pass with a wheelchair and to maintain a safe distance from cars. To them, width means usable or walkable width. Walkable width narrows when a sidewalk has construction, parked cars, unkempt greenery and utility or light poles on it, all of which evoked negative responses. Separation of the sidewalk from motorized traffic by parked cars, bollards or vegetation was perceived as positive. Lastly, they said they disliked sidewalks that had high ramps to get on or off, slopes or stairs, because these elements increased the difficulty of walking. The presence of safe crossings was mentioned by some participants. Zebra crossings, supplemented with traffic lights in busy streets, were considered necessary to be able to cross streets safely. Participants reported to deviate from their shortest route in order to use a zebra crossing or traffic light to safely cross the street. Some participants expressed safety concerns related to the behaviors of other road users. Participants liked streets with slow traffic and disliked streets with speeding cars. This topic was mostly discussed near street crossings, especially when approaching cars were not visible (e.g. near sharp turns). Participants proposed solutions like speed bumps and chicanes to slow down traffic. On the other hand, participants also mentioned car drivers being very courteous and giving priority to pedestrians at crossings. Not only speeding cars were disliked but careless cyclists on sidewalks were mentioned as dangerous as well.

7.3 Methods

7.3.1 Participants and questionnaire

In order to investigate which critical issues old pedestrians found in the pedestrian paths they usually walk and how their age related declines in perceptual and physical abilities and their experiences as road user can affect the opinion on the critical issues of pedestrian paths, a survey was developed. The investigation techniques based on surveys represent a very effective tool for the study of lot of issues of transport interest [36-41]. These techniques especially become indispensable when it is not possible to evaluate through experimental investigations the indicators associated with the subjective judgments of different road users.

A 22 items questionnaire was used to collect the participants' opinions. The questionnaire was divided into the following 5 sections:

- Section 1: participants reported their age, their gender and other basic socio-demographic characteristics information in the first section;
- Section 2: this section included questions regarding the experience as road users of participants. Participants were asked if they ever had the driving license, if they still drove, if they ever had accidents while driving and if they ever had accidents as pedestrians;
- Section 3: the third section contained questions about the age related declines of perceptual and physical abilities. Participants were asked if they had vision problems, hearing problems and mobility problems.
- Section 4: this section consisted of an open-ended question related to the critical issues of pedestrian paths. Participants could express freely their opinion related to the critical issues and the problems they found in the pedestrian paths they usually walked.
- Section 5: this section consisted of an open-ended question related to the solutions for critical issues of pedestrian paths. Participants could express freely their opinion related to the solutions they thought could improve the safety of pedestrian paths they usually walked.

The questionnaire underwent thorough piloting and revision, through 20 interviews face to face. This was done to ensure the suitability of the questions for the target people and to assess the acceptability of the wording, as well as the understanding of the questions.

Since the aim of this study was to explore the perception of old pedestrians of the critical issues of pedestrian paths, this study focuses on the first four sections of the questionnaire.

The survey was conducted in 5 different locations in Catania, Italy. The locations were specifically chosen near to attraction poles for old pedestrians (e.g. centers for the elderly, squares, churches). Participants were recruited in person, so as to select exclusively people over 70. Participants were briefed of the nature and time required to participate in the study prior to commencement. After their consent was obtained, the questionnaire started. It was decided to question directly the participants, instead of leaving them alone with the questionnaire, in order to provide visual aids and detailed explanations and clarifications. Each survey lasted approximatively 20 minutes. Participants were assured of anonymity and confidentiality.

The total sample comprised 322 participants (164 men and 158 women). Participants who didn't complete the questionnaire or who gave uncertain answers were excluded. The respondents excluded were about 5% of the sample. The final sample was composed by 306 participants (156 men and 150 women). The majority of respondents (50.33%) were aged between 70 and 75. 28.10% of respondents were aged between 75 and 80 and 21.57% of respondents were over 80.

7.3.2 Analytical method

In order to analyze the survey data a cluster analysis was carried out. Cluster analysis is a multivariate data exploration method. The primary objective of this analysis is to identify groups or “clusters” based on the similarities between the data points or a “natural” grouping. This can be done with a single data point or a combination of data points of interest such a series of questionnaires. There are several ways to perform a cluster analysis, but the two primary methods are K-Means and Hierarchical.

K-Means clustering is the most commonly used unsupervised machine learning algorithm for partitioning a given data set into a set of k groups (i.e. k clusters), where k represents the number of groups pre-specified by the analyst. It classifies objects in multiple groups (i.e., clusters), such that objects within the same cluster are as similar as possible (i.e., high intra-class similarity), whereas objects from different clusters are as dissimilar as possible (i.e., low inter-class similarity). In K-Means clustering, each cluster is represented by its center (i.e., centroid) which corresponds to the mean of points assigned to the cluster.

The first step when using K-Means clustering is to indicate the number of clusters (k) that will be generated in the final solution. The algorithm starts by randomly selecting k objects from the data set to serve as the initial centers for the clusters. The selected objects are also known as cluster means or centroids. Next, each of the remaining objects is assigned to its closest centroid, where closest is defined using the Euclidean distance between the object and the cluster mean.

This step is called “cluster assignment step”. After the assignment step, the algorithm computes the new mean value of each cluster. The term cluster “centroid update” is used to design this step. Now that the centers have been recalculated, every observation is checked again to see if it might be closer to a different cluster. All the objects are reassigned again using the updated cluster means. The cluster assignment and centroid update steps are iteratively repeated until the cluster assignments stop changing (i.e. until convergence is achieved). That is, the clusters formed in the current iteration are the same as those obtained in the previous iteration.

The basic idea behind K-Means clustering consists of defining clusters so that the total intra-cluster variation (known as total within-cluster variation) is minimized. There are several K-Means algorithms available. The standard algorithm is the Hartigan-Wong algorithm (1979), which defines the within-cluster variation as the sum of squared distances Euclidean distances between items and the corresponding centroid:

$$\mathrm{W}(\mathrm{C_k}) = \sum_{x_i \in C_k} (x_i - \mu_k)^2$$

where:

- W(Ck) = total within-cluster variation
- xi = a data point belonging to the cluster Ck
- μ_k = the mean value of the points assigned to the cluster Ck

Each observation (xi) is assigned to a given cluster such that the sum of squares (SS) distance of the observation to their assigned cluster centers (μ_k) is minimized.

So, the final goal of K-Means is to minimize the total within-cluster sum of square.

$$\mathrm{Tot.\,within - cluster} = \sum_{k=1}^{k} \mathrm{W}(\mathrm{C_k}) = \sum_{k=1}^{k} \sum_{x_i \in C_k} (x_i - \mu_k)^2$$

This quantity also measures the compactness (i.e. goodness) of the clustering.

The second approach to a cluster analysis is the Hierarchical method. In contrast to K-Means, in the hierarchical method clusters are merged based on distance from each other. The method considers each data point as its own individual data point and then clusters data points based on the distance between each data point. At first, each data point is grouped with the data point closest to it as defined by one of the linkage methods for hierarchical clustering defined below:

- Single Linkage: the distance between the closest data points of the two clusters.
- Complete Linkage: the distance between the data points of the two clusters which are the farthest apart from each other.
- Average Linkage: comparing between all pairs and averages of all distances. Also called UPGMA – Unweighted Pair Group Mean Averaging.
- Centroid Method: finding the mean vector location for each of the clusters and taking the distance between the two centroids.
- Ward’s Method: Uses statistical analysis methods such as error sum of squares and R-squared to determine groupings of data points.

Then, each of these groups is merged with the groups closest to its group mean, and so on. This continues until all groups have been merged.

The optimal number of clusters with the Hierarchical method is determined by the minimum number of groups with the maximum amount of distance between group means. Frequently, this is illustrated with a dendrogram of the merging clusters. Using a dendrogram, the ideal number of clusters is determined by the number of clusters intersected when drawing a vertical line through the largest horizontal distance between merging clusters.

7.3.3 Model development

Cluster analysis was used in this study in order to explore the safety perceptions of elderly pedestrians. Starting from the results of the survey, cluster analysis was developed to answer the following research questions:

1 - Can we group together old pedestrians with a similar perception of critical issues of pedestrian paths?

2 – How can we interpret the groups obtained? What do old pedestrians belonging to the same group have in common?

3 – Which variables do mostly affect the determination of the groups?

The nominal variable considered is “critical issues of pedestrian paths”, with the sixteen possible items showed in Table 1. These items were deduced from the open-ended question related to the critical issues of pedestrian paths of Section 4 of the questionnaire.

Table 1 - Nominal variable: critical issues of pedestrian paths.

Critical issues of pedestrian paths	
1	Sidewalks too narrow
2	Absence of sidewalks
3	Uneven sidewalks
4	Presence of obstacles on sidewalks
5	Absence of pedestrian crossing
6	Faded pedestrian crossing
7	Incorrect positioning of pedestrian crossing
8	Absence of ADA ramps on sidewalks
9	Vehicles parked on the sidewalks
10	Parked vehicles that obstruct pedestrian crossing
11	Inadequate drivers’ behavior
12	Damaged road pavement
13	Roadway too narrow and absence of sidewalks
14	Absence or inadequacy of street lighting
15	Absence or inadequacy of signalized pedestrian crossings
16	Other

The 8 variables considered are instead showed in Table 2. The variable *No driving license* indicates whether the respondents had not ever got the driver license, that means whether the respondents had not ever drove. The variable *No still driving* indicates whether the respondents were not still driving when they answered the questionnaire. The variable *Accidents driving* indicates whether the respondents had ever had an accident when they were driving. The variable *Accidents pedestrian* indicates whether the respondents were ever hit by a car (or another vehicle) when they were walking. The variables *Vision problems, Hearing problems* and *Mobility problems* indicates whether the respondents have vision, hearing or mobility problems respectively. These variables are therefore representative of the respondents’ age related declines in perceptual and physical abilities of respondents. Finally, the variable *Gender* of respondents was included in the analysis.

Table 2 - Variables used for the cluster analysis.

No driving license	No	66,67%	Yes	33,33%
No still driving	No	48,37%	Yes	51,63%
Accidents driving	No	39,87%	Yes	60,13%
Accidents pedestrian	No	24,18%	Yes	75,82%
Vision problems	No	52,94%	Yes	47,06%
Hearing problems	No	32,03%	Yes	67,97%
Mobility problems	No	24,18%	Yes	75,82%
Gender	Male	50,98%	Female	49,02%

7.4 Results and discussion

7.4.1 K-Means cluster analysis

As shown in Table 3, critical issues of pedestrian paths were grouped in clusters by using SPSS software. To use K-Means clustering, the number of clusters is arbitrarily determined, either from existing knowledge of the data and the approximate number of groups you want to divide the data into. Of course, a good approach to K-Means is to try several numbers of clusters and see which number best represents the data or produces any significant differences in analysis. Different models of clusters were therefore estimated, from one to seven, for selecting the suitable number of clusters. For further analysis, the critical issues of pedestrian paths were divided into five clusters. Table 3 shows the clusters membership. The first cluster is composed only by item 10, i.e. “parked vehicles that obstruct pedestrian crossing”. This cluster can therefore be named *Irregular parking.* Cluster 2 is composed only by item 2, i.e. “absence of sidewalks”. The second cluster can therefore be named *Absence of sidewalks*. The third cluster groups together 9 items, i.e. item 1 (“sidewalks too narrow”), item 3 (“uneven sidewalks”), item 4 (“presence of obstacles on sidewalks”), item 7 (“incorrect positioning of pedestrian crossing”), item 9 (“vehicles parked on the sidewalks”), item 12 (“damaged road pavement”), item 13 (“roadway too narrow and absence of sidewalks”), item 15 (“absence or inadequacy of signalized pedestrian crossings”), item 16 (“other”). Cluster 3 can therefore be named *Problems of sidewalks and of the correct use of pedestrian crossings*. Cluster 4 is composed only by item 14, i.e. “absence or inadequacy of street lighting”. The fourth cluster can therefore be named *Absence or inadequacy of street lighting*. Finally, Cluster 5 groups together 4 items, i.e. item 5 (“absence of pedestrian crossing”), item 6 (“faded pedestrian crossing”), item 8 ("absence of ADA ramps on sidewalks") and item 11 ("inadequate drivers' behavior"). Cluster 5 can therefore be named *Problems of pedestrian crossings and of drivers' behavior*.

Table 3 - Clusters membership.

Critical issues of pedestrian paths	Cluster	Distance
1	3	0.242
2	2	0.000
3	3	0.185
4	3	0.244
5	5	0.286
6	5	0.247
7	3	0.420
8	5	0.365
9	3	0.238
10	1	0.000
11	5	0.327
12	3	0.432
13	3	0.277
14	4	0.000
15	3	0.318
16	3	0.314

Table 4 - ANOVA analysis results.

	Cluster Mean Square	df	Error Mean Square	df	F	Sig.
No driving license	0.083	4	0.006	11	13.109	**0.000**
No still driving	0.137	4	0.010	11	13.987	**0.000**
Accidents driving	0.101	4	0.024	11	4.122	**0.028**
Accidents pedestrian	0.028	4	0.020	11	1.393	0.299
Vision problems	0.109	4	0.012	11	9.018	**0.002**
Hearing problems	0.039	4	0.016	11	2.363	0.117
Mobility problems	0.037	4	0.015	11	2.381	0.115
Gender	0.148	4	0.008	11	19.157	**0.000**

Table 4 shows the ANOVA analysis results and allows to understand which variables affect more the identification of the clusters. The variables mostly contributing to the identification of the clusters are *Driving license* (Sig.=0.000), *Still driving* (Sig.=0.000), *Gender* (Sig.=0.000), *Vision problems* (Sig.=0.002) and

Accidents driving (Sig=0.028). *Accidents pedestrian* (Sig=0.299), *Hearing problems* (Sig=0.117) and *Mobility problems* (Sig=0.115) are instead the variables less affecting the division into different clusters.

The judgment expressed by the elderly on the critical issues of pedestrian paths seems to be significantly linked to gender, to the experience as road users, and to vision problems that compromise the correct perception of the road environment. On the other hand, the least significant variable in conditioning the judgment on critical issues is that associated with road accidents that respondents had pedestrians. Hearing and mobility problems, even if conditions the perception of urban pedestrian paths, are less significant than sight problems. Basically, in identifying the critical issues of pedestrian paths, the elderly are mainly conditioned by the difficulty of correctly seeing the paths themselves and of perceiving the information deriving from the road environment as a whole.

Table 5 shows the profiles of the clusters obtained with the K-Means procedure. Each group is represented by a center which originate a vector (row) whom components are the means of the values of the variables that defines the coordinates of the objects belonging to that group. The final cluster centers can range from 0 to 1. The closer the value is to 1, the closer is the condition “Yes” expressed by the variable (except for the variable *Gender* for which the closer the value is to 1 the more are women than men). These conditions are all representative of age related declines in perceptual and physical abilities (vision, hearing and mobility problems) or of experiences as road user (no driving license, no still driving, accidents driving, accident pedestrian) which can affect the opinion on the critical issues of pedestrian paths.

The characteristics of the five clusters are given below.

- Cluster 1 (*Irregular parking)*: All respondents of this group are men. Moreover, the majority of respondents belonging to this group had accidents while driving.
- Cluster 2 (*Absence of sidewalks*): This group is mainly composed by women who don’t drive anymore, who never had the driving license and have vision and hearing problems.
- Cluster 3 (*Problems of sidewalks and of the correct use of pedestrian crossings*): Table 5 shows that no particular characteristics of respondents belonging to this group can be identified. This suggests that respondents who identify these critical issues of pedestrian paths don’t have particular characteristics. This also suggests that critical issues

associated to cluster 3 are commonly perceived by pedestrians regardless of age related declines in perceptual and physical abilities and regardless of their experiences as road users.

- Cluster 4 (*Absence or inadequacy of street lighting*): All respondents of this group had accidents while driving and are men.
- Cluster 5 (*Problems of pedestrian crossings and of drivers' behavior*): Table 5 shows that no particular characteristics of respondents belonging to this group can be identified. This suggests that respondents who identify these critical issues of pedestrian paths don't have particular characteristics. As with cluster 3, the critical issues associated to cluster 5 are commonly perceived by pedestrians regardless of age related declines in perceptual and physical abilities and regardless of their experiences as road users.

Table 5 - Final cluster centers.

	Cluster				
	1	2	3	4	5
No driving license	0.00	**0.68**	0.29	0.00	0.21
No still driving	0.45	**0.91**	0.52	0.00	0.30
Accidents driving	**0.82**	0.55	0.46	**1.00**	0.41
Accidents pedestrian	0.45	0.31	0.23	0.00	0.27
Vision problems	0.73	**0.78**	0.62	0.40	0.28
Hearing problems	0.27	**0.52**	0.25	0.00	0.18
Mobility problems	0.45	0.30	0.13	0.00	0.22
Gender	**0.00**	**0.78**	0.50	**0.00**	0.29

Table 6 shows the Euclidean distances between the final cluster centers. The higher is this distance, the higher is the difference between groups. It can be seen that the distance between cluster 3 and cluster 5 is the minimum (0.478). That is a confirmation of the fact that cluster 3 and cluster 5 are similar. For both these clusters, indeed, no particular characteristics of respondents were identified.

Table 6 - Distances between final cluster centers.

Cluster					
	1	2	3	4	5
1		1.209	0.793	0.906	0.791
2	1.209		0.725	1.644	1.109
3	0.793	0.725		1.034	**0.478**
4	0.906	1.644	1.034		0.858
5	0.791	1.109	**0.478**	0.858	

Table 7 summarizes the "profiles" of the elderly pedestrians identified in relation to the 5 clusters defined by means of the K-Means cluster analysis. The following considerations can be made:

1) the critical issues concerning the correct use of sidewalks and pedestrian crossings (cluster 3 and cluster 5) are not associated with a specific "profile" of elderly pedestrian. These critical issues, therefore, constitute a safety deficit highlighted in a systematic manner by almost all the sample of users interviewed;
2) also the problems related to aggressive drivers' behavior are highlighted almost indiscriminately by all the respondents;
3) the problem of irregular parking (cluster 1) and the problems related to the absence or inadequacy of street lighting (cluster 4) are mainly indicated by men who had driving accidents during their experience as road users.
4) the "profile" constituted by women who have never driven and who have sight and hearing problems is associated with the problems related to the absence of sidewalks (cluster 2).

Table 7 - Profiles of the elderly pedestrians obtained from the K-Means cluster analysis.

		Variables							
Cluster		Gender	No driving license	No still driving	Accidents driving	Accidents pedestrian	Vision problems	Hearing problems	Mobility problems
1	Irregular parking	🚹			✓				
2	Absence of sidewalks	🚺	✓	✓			✓	✓	
3	Problems of sidewalks and of the correct use of pedestrian crossings								
4	Absence or inadequacy of street lighting	🚹			✓				
5	Problems of pedestrian crossings and of drivers' behavior								

7.4.2 Hierarchical cluster analysis

Hierarchical clustering allows to confirm the number of clusters which was hypothesized with the K-Means clustering. The optimal number of clusters with the hierarchical method is determined by the minimum number of groups with the maximum amount of distance between group means. Frequently, this is illustrated with a dendrogram of the merging clusters. Using a dendrogram, the ideal number of clusters is determined by the number of clusters intersected when drawing a horizontal line through the largest vertical distance between merging clusters. Similar to K-Means, the optimal value of clusters must be chosen, but this method gives some perspective as to what the ideal value may be.

The hierarchical clustering allowed to illustrate the hierarchical organization of groups as shown in the dendrogram of Figure 1. This visualization confirms the previous result, but offers also a hierarchical view of the clusters. By cutting the dendrogram at height 6, corresponding to the highest jump between levels of similarity, five clusters homogeneous as for their level of perceived safety are obtained. These clusters correspond to the five clusters resulting from the K-Means cluster analysis. The hypothesis made for K-Means cluster analysis was therefore fully confirmed by hierarchical cluster analysis.

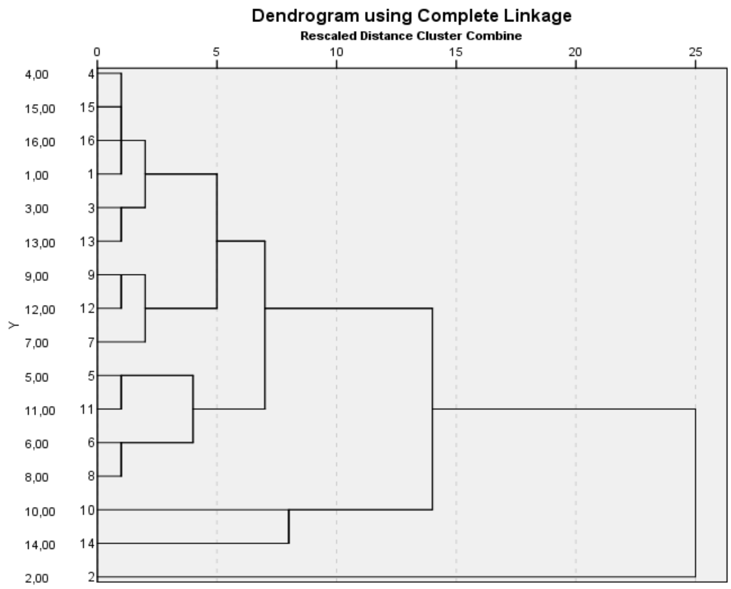

Figure 1 - Hypothesis scheme.

7.5 Conclusion

It is widely recognized that human factors may contribute to accident involvement in traffic [42,43]. The literature on human factors and road user behavior is extensive (e.g. [44, 45]). The understanding of pedestrian behavior in urban contests may assist to improve design and planning of road and traffic environment, and consequently to improve of pedestrian comfort and safety. It has also been shown that road and traffic factors alone may explain only a small part of pedestrian walking and crossing behavior in urban areas [46]. However, human factors related to pedestrians have received less attention in the literature compared to other road users [47].

This study wants therefore to understand how human factors influence elderly pedestrian perception of critical issues of pedestrian paths. The aspects related to human factors considered are the gender, the factors associated with the experience as road users and the factors related to age related problems (mobility, vision and hearing problems). More specifically, the final aim is to capture and analyze the key components that influence the elderly pedestrians' perception of pedestrian paths and to identify how these perceptions change for different pedestrian "profiles" based on human factors.

The results show that the judgment expressed by the elderly on the critical issues of pedestrian paths they usually walk is significantly linked to gender, to their experience as road users, and to vision problem, which compromise the correct perception of the road environment. However, cluster analysis allowed to identify few "profiles" of elderly pedestrians with regard to their perception of critical issues of pedestrian paths. These findings should be considered in light of the limitations of the present research. Extending this questionnaire survey to a larger and more representative sample may reveal additional critical issues and additional "profiles" of elderly pedestrians.

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8. CONCLUSIONS

The road transport sector is currently adopting growing measures to prevent accidents and reduce their consequences on people, especially on the most vulnerable users (e.g., pedestrians and cyclists). Urban areas are characterized by different types of road users. Road users are different for age, gender, social extraction, cultural level, driving experience, familiarity with different means of transport, etc. A child, for example, is an "actor" of the urban mobility exclusively as pedestrian or cyclist and has a road experience completely different from a professional bus driver. And yet both of them coexist in the same urban environment. Similar considerations can be done for the elderly, disabled, professionals, workers and much more. So urban road contexts are characterized by a significant heterogeneity of human factors. Human factors have been reported to account for the occurrence of 90 % of all road traffic accidents. At the same time, road safety experts acknowledge that human factors are insufficiently considered in the design of roads. A better understanding of how human factors and road users' behaviour should therefore be incorporated in the design of roads in urban areas. Road users' behaviour is largely determined by a combination of factors, including the road infrastructure, road traffic regulations, levels of traffic law enforcement, in-vehicle safety technology, behaviour of other road traffic participants and traffic education. Road traffic system designers should support and guide road users to act safely in traffic by designing self-explaining and self-enforcing roads. Urban areas are characterized by the presence of different type of road users. So the infrastructure and vehicle developments can deliver the highest levels of road safety if all road users, including vehicle drivers, cyclists and pedestrians act safely. It is therefore necessary to study how different road users of urban areas act in different road elements and how they perceive different solutions.

This dissertation presents an analysis of human-road interaction in urban areas for different road users and for different road elements. Six case studies analysing this interaction with different approaches were presented in the dissertation. The road elements analysed are the road intersections with particular reference to the roundabouts (chapters 2,3,5,6) and the pedestrian paths (chapter 4 and 7). Human factors, such as age and gender, were taken into account in each study even if they were not considered as effective variables in each case. Chapter 3, for example, refers only to young people, chapter 4 refers to children, chapter 5 and 6 refers to adults, while chapter 7 refers to old people. Drivers are the type of road users analysed in the majority of the studies (Chapters 2, 3, 5). Chapter 4 and Chapter 7 regards the behaviour of pedestrians, while Chapter 6 regards the behaviour of bicyclists. In each study the correlations between the user and the road were studied with the support of experimental investigations and using different methodologies of statistical analysis. The results obtained are helpful in terms of improving the safety of urban road infrastructures. The main findings of each study are summarised below.

Chapter 2 focuses on drivers' safety perception of roundabouts during the execution of the different manoeuvres (entry, circulation, exit). The final aim is to understand how different geometric characteristics (single or double lane on the entry leg, on the exit leg and on the circulatory roadway) affect drivers' perception. The considerations arising from the final model are the following: 1) the respondents' opinions regarding the safety perception of manoeuvres are not preconceived ideas, but they originate from specific safety perceptions due to roundabout geometric configurations; 2) the users prefer definitely single lane roundabouts; 3) it was quantified the extent of the relationship between the safety perception of the typical roundabout manoeuvres and the following aspects: a) manoeuvre type, b) geometric characteristics of the roundabouts design elements.

Chapter 3 investigates the risk perception of roundabouts for young people. The research findings provide insight into young people risk perception of roundabouts: traffic conditions strongly affect risk perception of roundabouts; the roundabouts with small circulatory roadway (smaller than 7 m), with a diameter less than 40 m and with one lane on the legs and on the circulatory roadway are generally perceived as more dangerous than those with a medium/large circulatory roadway (larger than 7 m), with a diameter longer than 40 m and with two lanes n the legs and on the circulatory roadway; the right-turn bypass lane affects the respondents risk perception.

Chapter 4 examines children's safety perception of home-school paths based on their parents' opinions. The methodology used allowed to understand which elements favour parents' willingness to "trust" safe home-school paths in order to let their children walk to school. At the same time the data of the survey were used to evaluate parents' safety perception of the existing home-school paths and understand a correlation between the choice of walking or of driving to school.

Results showed that the main reasons why parents drive their children to school are the lack of safe home-school paths and the availability of regular or irregular parking spaces near the school. Results furthermore suggest that infrastructure-centred interventions, such as traffic calming measures and safer pedestrian crossings, can increase parents' safety perception of the home-school paths and thus raise the probability that children walk to school.

Chapter 5 analyses drivers' physiological and behavioural responses when approaching T-junctions and roundabouts. The ultimate aim was to understand how at grade intersections affect the driving behaviour by comparing speed and electrodermal activity variations induced by roundabouts and by T-junctions. Two different analysis were developed in order to make this comparison. The first analysis showed that the number of SCR peaks as well as the amplitude of the peaks are overall higher for the two manoeuvres on the roundabout. The stress level induced by each type of intersection was evaluated through an Electrodermal Impact Index which takes into account both the number and the amplitude of SCR peaks. The results are particularly interesting as they suggested that the stress level induced by roundabouts is more than double that induced by standard intersections. The second analysis explicitly confirmed the existence of a link between driving behaviour and physiological parameters. Results highlight that T-junctions induce low variations in electrodermal activity and are often associated with a significant speed increase, while roundabouts strongly affects drivers' behaviour, inducing significant electrodermal activity and speed reductions.

Chapter 6 makes use of semi-automated video observation software with the aim of analysing bicyclist behaviour and bicyclist safety on roundabouts with different diameters. The motivation for this study was to understand better bicyclist behaviour and how it varies under different conditions. Observations at four roundabouts with mixed traffic revealed that free-flow bicyclists ride significantly faster on roundabouts with bigger diameter compared to roundabouts with smaller diameter. It was also observed that free-flow bicyclists tend to choose lateral positions less constraining in terms of resistances (i.e. lateral positions far from the external edge of the circulatory roadway). This is more evident on roundabouts with bigger diameter, probably because bigger radii of trajectories favour the predisposition to ride close to the central island. The analysis of bicyclists' behaviour with regard to the use of helmet that free-flow bicyclists using helmet ride faster than free-flow bicyclists without helmet. The same consideration is valid for bicyclists using reflective devices, who were found to ride faster than bicyclists not using reflective devices.

The analysis of speed and lateral positions for different conditions showed that regardless of the type of condition (free-flow or different interactions), bicyclists always ride faster and closer to the central island on roundabouts with bigger diameter. Results shows also that bicyclists are strongly conditioned by the presence of the following vehicle in roundabouts and are therefore inclined to ride closer to the external edge of the circulatory roadway, both for roundabouts with bigger and smaller diameter. This is probably due to the fact that bicyclists don’t feel confident and safe while followed by a vehicle and tend therefore to assume a more external position in order to favour the overtaking.

Chapter 7 examines how human factors influence elderly pedestrian perception of critical issue of pedestrian paths. The aspects related to human factors considered are the gender, the factors associated with the experience as road users and the factors related to age related problems (mobility, vision and hearing problems). More specifically, the final aim is to capture and analyze the key components that influence the elderly pedestrians’ perception of pedestrian paths and to identify how these perceptions change for different pedestrian "profiles" based on human factors. The results show that the judgment expressed by the elderly on the critical issues of pedestrian paths they usually walk is significantly linked to gender, to their experience as road users, and to vision problem, which compromise the correct perception of the road environment.

The studies performed within the frame of this doctoral dissertation have led to a deeper insight into human-road interaction in urban areas for different road users and for different road elements. The results suggest that changing the road environment taking into account the human capabilities and limitations can contribute to the reduction of road users’ mistakes. However, removing completely them is a utopian imagination. The case studies of this dissertation have also led to safety-relevant insights into some topics that have rarely been addressed in scientific literature before from the point of view of the road user. Even though further research on the studied case study topics is needed, this dissertation has been able to provide some valuable first insights into a number of policy-relevant road safety topics by using a combination of road users’ perception and behavioural aspects. It seems that a stronger emphasis on the influence of human factors could lead to stronger evidence of the expected safety effects. The human-road interaction in urban areas for different road users and for different road elements has been analysed in this dissertation. Further research on human-road interaction in urban areas for other types of road users and for other types of road elements is needed in order to further understand how to improve road design in urban areas taking into account the need of different road users.