IATSS Research xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

IATSS Research

Research article

Factors with the greatest influence on drivers' judgment of roundabouts safety. An analysis based on web survey in Italy

Natalia Distefano, Salvatore Leonardi *, Giulia Pulvirenti

Department of Civil Engineering and Architectural, University of Catania, Viale Andrea Doria, 6 - 95125 Catania, Italy

ARTICLE INFO

Article history:
Received 11 October 2017
Received in revised form 19 February 2018
Accepted 6 April 2018
Available online xxxx

Keywords:
Road safety
Statistical analysis
Dimensionality reduction methods
Roundabout design
Driving behavior

ABSTRACT

The aim of this paper is to identify the roundabout geometric characteristics affecting the safety perception while the typical maneuvers (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 analyze the data collected from the survey, in order to examine the key factors affecting the safety perception during the typical roundabout maneuvers. The considerations arising from the final model are the following: 1) the respondents' opinions regarding the safety perception of maneuvers are not preconceived ideas, but they originate from specific safety perceptions due to roundabout geometric configurations; 2) the users prefer definitely single lane roundabouts; this is an important confirmation of most results in the literature; 3) it was quantified the extent of the relationship between the safety perception of the typical roundabout maneuvers and the following aspects: a) maneuver 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.

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 behavior. 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 behavior 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 behaviors in order to accommodate the direct experiences we have as road users. Among 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 behavior 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

* Corresponding author at: Department of Civil Engineering and Architectural (DICAR), University of Catania, Viale Andrea Doria, 6 - 95125 Catania, Italy.
E-mail addresses: ndistefa@dica.unict.it, (N. Distefano), sleona@dica.unict.it, (S. Leonardi), giulia.pulvirenti@unict.it. (G. Pulvirenti).
Peer review under responsibility of International Association of Traffic and Safety Sciences.

https://doi.org/10.1016/j.iatssr.2018.04.002

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 analyzed to develop an in-depth understanding of the behavior 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 behavior. These factors occasionally cause incorrect behaviors 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 maneuvers: entry maneuver, exit maneuver and maneuver on the circulatory roadway. However, the judgment on how dangerous these maneuvers 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 behavior 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 maneuvers (entry, circulation, exit). The tool used was an on-line questionnaire, filled out by about 1.650 respondents. In order to analyze 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 analyze 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 analyze the driver behavior [18–20].

Some researchers applied more than one of these analyses to examine the data thoroughly. For example, Usami et al. [21] studied behavioral 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 behaviors. Arnau-Sabates et al. [22] used factorial and Cluster

Please cite this article as: N. Distefano, et al., Factors with the greatest influence on drivers' judgment of roundabouts safety. An analysis based on web survey in Italy, IATSS Research (2017), https://doi.org/10.1016/j.iatssr.2018.04.002

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 analyze the data collected from an on-line questionnaire, in order to examine the key factors affecting the safety perception during the typical roundabout maneuvers. The final aim was the evaluation of the influence of roundabout design options on the perceived safety during the different maneuvers.

2. Methodology

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 maneuvers (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.

Fig. 1 schematically shows the 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 Center 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 maneuvers, the results of the fourth section of the questionnaire were analyzed. Table 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.

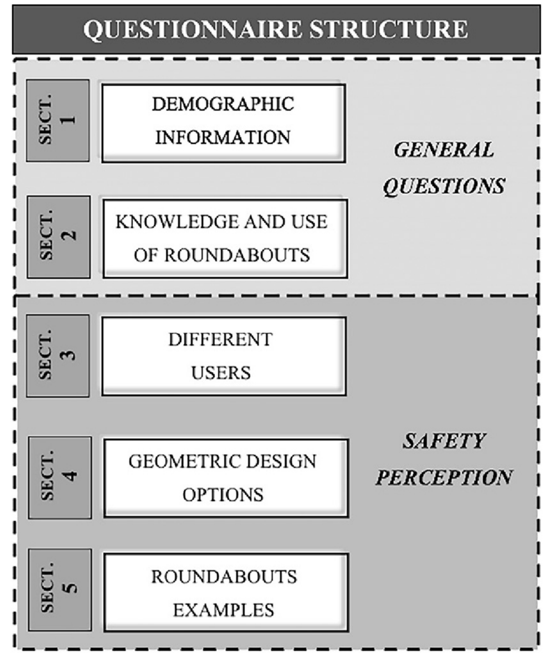

Fig. 1. Questionnaire structure.

Table 1
Section 4 questions.

Questionnaire – Section 4	
Which do you think is the most dangerous maneuver on a roundabout?	Entry maneuver Maneuver on the circulatory roadway Exit maneuver
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

Please cite this article as: N. Distefano, et al., Factors with the greatest influence on drivers' judgment of roundabouts safety. An analysis based on web survey in Italy, IATSS Research (2017), https://doi.org/10.1016/j.iatssr.2018.04.002

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.

2.3. Methods for analysis and model development

Carrying out a thorough analysis of the key factors affecting the safety perception during the typical roundabout maneuvers was the final aim of this study. The method selected to conduct this analysis was the Structural Equation Modeling. Structural Equation Modeling (SEM) is notoriously a very general statistical modeling technique widely used in the field of behavioral 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 modeled 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 maneuvers were discovered using Correspondence Analysis (CA) and Cluster Analysis. The Correspondence Analysis (CA) is a descriptive method for analyzing 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 3 (S1, S2, …, S13); variable 2 describes the types of users according to their safety perception about the three possible roundabout maneuvers by means of 3 items (U1, U2 and U3) listed in Table 3.

The data used for the Correspondence Analysis were also analyzed 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

Table 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

Table 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 maneuver the most dangerous
U2	Users who consider the exit maneuver the most dangerous
U3	Users who consider the maneuver on the circulatory roadway the most dangerous

Please cite this article as: N. Distefano, et al., Factors with the greatest influence on drivers' judgment of roundabouts safety. An analysis based on web survey in Italy, IATSS Research (2017), https://doi.org/10.1016/j.iatssr.2018.04.002

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 maneuver the most dangerous; n = 195, for users considering the maneuver on the circulatory roadway the most dangerous; n = 582, for users considering the exit maneuver 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.

3. Results and discussions

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 Fig. 2.

As it can be seen from Fig. 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 maneuvers (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 maneuvers (single-lane configurations with special regard to consecutive single-lane elements); on the right, there are the items

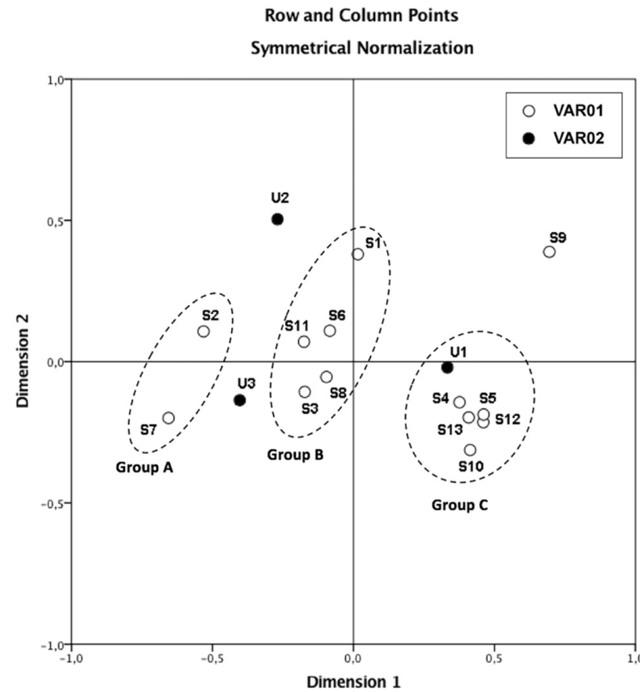

Fig. 2. CA biplot of all study variables.

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).

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 2.3, 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 Fig. 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.

Fig. 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 maneuvers. Nevertheless, the first item (users considering the entry maneuver 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.

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).

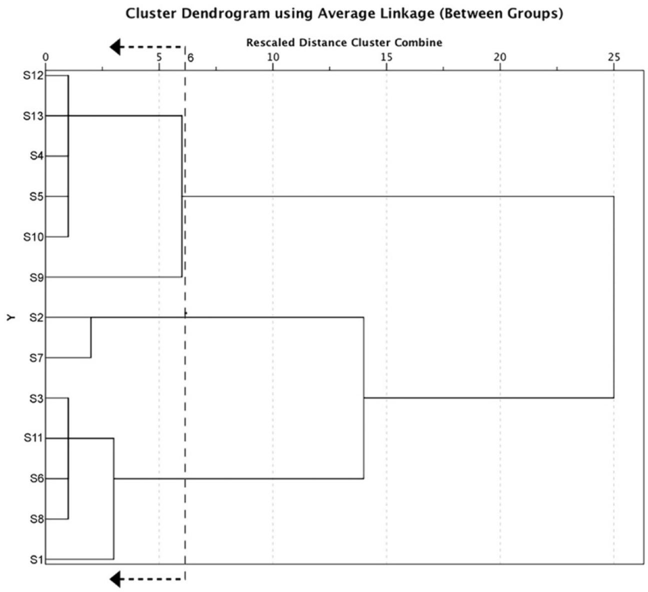

Fig. 3. Cluster Analysis dendrogram of safety perception variable.

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 maneuver the most dangerous in roundabout; 2) portion of the answers database ($N = 195$) given by users who considered the maneuver on the circulatory roadway the most dangerous in roundabout; 3) portion of the answers database ($N = 582$) given by users who considered the exit maneuver the most dangerous in roundabout.

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

3.2.1. Results related to users who consider the entry maneuver the most dangerous

The output of the Exploratory Factor Analysis for users who consider the entry maneuver the most dangerous is the pyramid diagram of the safety perception shown in Fig. 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).

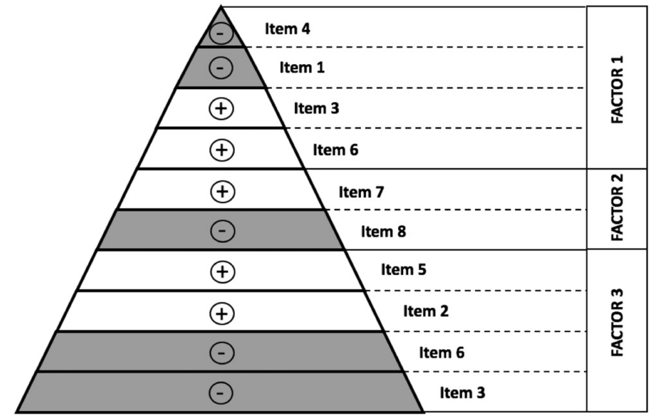

Fig. 4. EFA Pyramid diagram (users who consider the entry maneuver the most dangerous).

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 Fig. 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 maneuver on the circulatory roadway. Therefore, the second factor is named “Importance of one circulating lane for the safety of the maneuver on the circulatory roadway”;
- the items saturating the third factor show that the safety perception for entry and exit maneuvers 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 maneuvers”.

The Exploratory Factor Analysis, ultimately, shows that:

- according to users who consider the entry maneuver 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 maneuver 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):

Please cite this article as: N. Distefano, et al., Factors with the greatest influence on drivers' judgment of roundabouts safety. An analysis based on web survey in Italy, IATSS Research (2017), https://doi.org/10.1016/j.iatssr.2018.04.002

- 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 Fig. 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 maneuver 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 maneuver 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.

3.2.2. Results related to users who consider the maneuver on the circulatory roadway the most dangerous

The output of the Exploratory Factor Analysis for users who consider the maneuver on the circulatory roadway the most dangerous is the pyramid diagram of the safety perception shown in Fig. 6.

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).

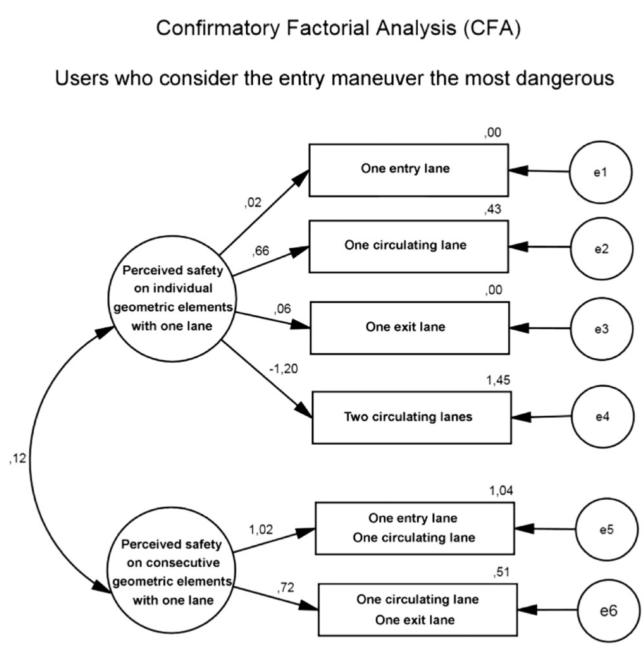

Fig. 5. CFA path diagram of the perceived safety by users who consider the entry maneuver the most dangerous.

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 Fig. 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 maneuver on the circulatory roadway. Therefore, the second factor is named "Importance of one circulating lane for the safety of the maneuver 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 Fig. 7. These results can be summarized as follows:

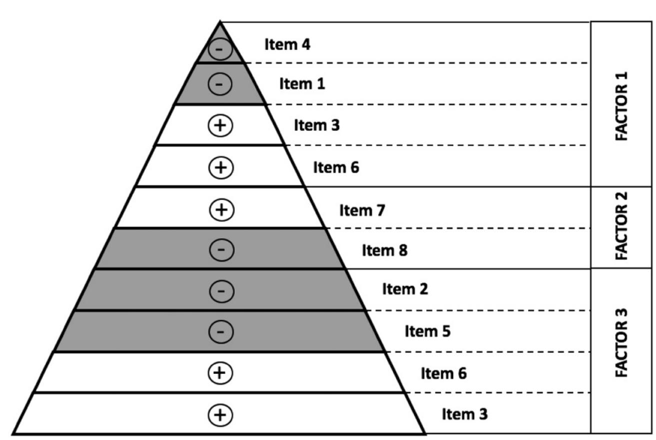

Fig. 6. EFA Pyramid diagram (users who consider the maneuver on the circulatory roadway the most dangerous).

Please cite this article as: N. Distefano, et al., Factors with the greatest influence on drivers' judgment of roundabouts safety. An analysis based on web survey in Italy, IATSS Research (2017), https://doi.org/10.1016/j.iatssr.2018.04.002

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

3.2.3. Results related to users who consider the exit maneuver the most dangerous

The output of the Exploratory Factor Analysis for users who consider the exit maneuver the most dangerous is the pyramid diagram of the safety perception shown in Fig. 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).

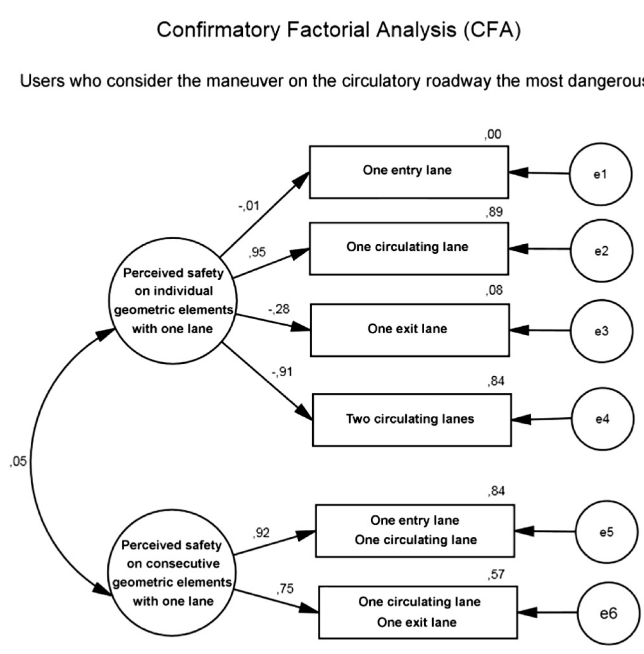

Fig. 7. CFA path diagram of the perceived safety by users who consider the maneuver on the circulatory roadway the most dangerous.

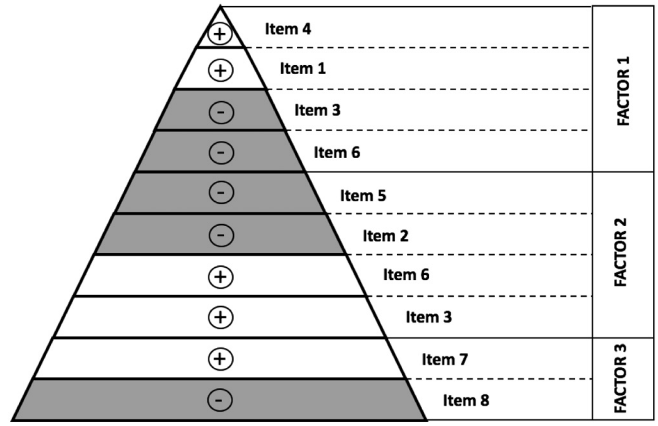

Fig. 8. EFA pyramid diagram (users who consider the exit maneuver the most dangerous).

From the analysis of the diagram of Fig. 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 maneuver 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 maneuver 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 maneuver 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 Fig. 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).

Please cite this article as: N. Distefano, et al., Factors with the greatest influence on drivers' judgment of roundabouts safety. An analysis based on web survey in Italy, IATSS Research (2017), https://doi.org/10.1016/j.iatssr.2018.04.002

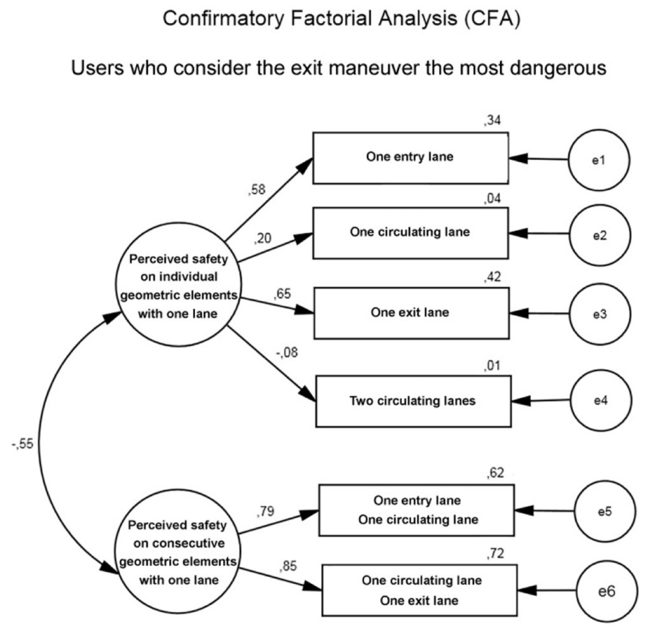

Fig. 9. CFA path diagram of perceived safety by users who consider the exit maneuver the most dangerous.

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

4. Conclusion

The purpose of this research was to evaluate the roundabout geometric characteristics affecting the safety perception during the typical maneuvers (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 maneuvers (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 modeling are the following:

- the respondents' opinions regarding the safety perception of maneuvers 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 maneuvers and the following aspects: a) maneuver 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 behavior. Obviously such understanding will also be crucial for the definition of new design criteria and/or for the improvement of the existing ones.

References

[1] W.K.M. Alhajyaseen, M. Asano, H. Nakamura, D. Minh Tan, Stochastic approach for modeling the effects of intersection geometry on turning vehicle paths, Transp. Res. C 32 (2013) 179–192.
[2] S. Anjana, M.V.L.R. Anjaneyulu, Safety analysis of urban signalized intersections under mixed traffic, J. Saf. Res. 52 (2015) 9–14.
[3] S. Anjana, M.V.L.R. Anjaneyulu, Development of safety performance measures for urban roundabouts in India, J. Transp. Eng. 141 (2015).
[4] R. Elvik, Road safety effects of roundabouts: a meta-analysis, Accid. Anal. Prev. 99 (2017) 364–371.
[5] S. Daniels, T. Brijs, E. Nuyts, G. Wets, Externality of risk and crash severity at roundabouts, Accid. Anal. Prev. 42 (2010) 1966–1973.
[6] H. Sadeq, T.S. Sayed, Automated roundabout safety analysis: diagnosis and remedy of safety problems, J. Transp. Eng. 142 (2016).
[7] S. Kim, J. Choi, Safety analysis of roundabout designs based on geometric and speed characteristics, KSCE J. Civ. Eng. 17 (2013) 1446–1454.
[8] B. Wang, D.A. Hensher, T. Ton, Safety in the road environment: a driver behavioural response perspective, Transportation 29 (2002) 253–270.
[9] A. Montella, Identifying crash contributory factors at urban roundabouts and using association rules to explore their relationships to different crash types, Accid. Anal. Prev. 43 (2011) 1451–1463.
[10] F. Gross, C. Lyon, B. Persaud, R. Srinivasan, Safety effectiveness of converting signalized intersections to roundabouts, Accid. Anal. Prev. 50 (2013) 234–241.
[11] M. Jalayer, H. Zhou, A multiple correspondence analysis of at-fault motorcycle-involved crashes in Alabama, J. Adv. Transp. 50 (2017) 2089–2099.
[12] R. Factor, G. Yair, D. Mahalel, Who by accident? The social morphology of car accidents, Risk Anal. 30 (9) (2010).
[13] B. Donmez, L. Boyle, J.D. Lee, Differences in off-road glances: effects on young drivers' performance, J. Transp. Eng. 136 (2010) 403–409.
[14] S. Oltedal, T. Rundmo, Using cluster analysis to test the cultural theory of risk perception, Transp. Res. F 10 (2007) 254–262.
[15] G. Vandenbulcke, I. Thomas, B. De Agues, B. Degraeuwe, R. Torfs, R. Meeusen, L.I. Panis, Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium, Transp. Policy 16 (2009) 77–87.
[16] H. Monterde i Bort, Factorial structure of recklessness: to what extent are older drivers different? J. Saf. Res. 35 (2004) 329–335.
[17] A. Sraji, N. Tjahjono, A confirmatory factor analysis of accidents caused by the motorcycle aspect in urban area, Int. J. Traffic Transpo. Eng. 2 (2012) 60–69.
[18] J.F. Dourado, A.T. Pereira, V. Noguiera, A.M.C. Bastos Silva, A.J.M. Seco, Personality and driver behaviour questionnaire: correlational exploratory study, in: Dell'Acqua, Wegman (Eds.),Transport Infrastructure and Systems, 2017.
[19] D. Toèplsek, D. Dragan, Behavioural comparison of driverswhen driving a motorcycle or a car: a structural equation modelling study, Promet Traffic Transpo. 27 (6) (2015) 457–466.
[20] O. Simsekoglu, T. Nordfjaern, The role of safety culture/climate and social cognitive factors for driving behaviors of Turkish professional drivers transporting petroleum products, J. Risk Res. 20 (5) (2017) 650–663.
[21] D.S. Usami, L. Persia, M. Picardi, M.R. Saporito, I. Corazziari, Identifying driving behaviour profiles by using multiple correspondence analysis and cluster analysis, in: Dell'Acqua, Wegman (Eds.),Transport Infrastructure and Systems, 2017.
[22] L. Arnau-Sabates, M.J. Garcia, M.M. Munoz, J.A.M. Capdveille, The relationship between awareness of road safety measure and accident involvement in pre-drivers: the basis of a road safety programme, J. Risk Res. 16 (5) (2013) 635–650.

Please cite this article as: N. Distefano, et al., Factors with the greatest influence on drivers' judgment of roundabouts safety. An analysis based on web survey in Italy, IATSS Research (2017), https://doi.org/10.1016/j.iatssr.2018.04.002