Unsafe driving behaviours at single-lane roundabouts: empirical evidence from CHAID Method

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Abstract. Even though roundabouts have been shown to provide significant safety and operational benefits, they generally are more complex and difficult to navigate than most other road segments. This study intends to contribute for a better understanding of the factors affecting the drivers' unsafe behaviours at single-lane roundabouts. Unsafe behaviours are evaluated based on the results of an on-road test around the suburbs surrounding the city of Catania. The unsafe behaviours observed during the on-road study were classified into three different categories: entry unsafe behaviours, circulation unsafe behaviours and exit unsafe behaviours. Three Chi Square Automatic Interaction Detection (CHAID) analysis were developed in order to analyse the influence of driver's characteristics, roundabout characteristics and manoeuvre on entry, circulation and exit unsafe behaviours respectively. Results show that the roundabout layout influences unsafe driving behaviours, while drivers' characteristics were not found to have influence on unsafe driving behaviours.

Keywords: Driver observation - On-road study - Human factor - Road safety - CHAID analysis.

1 Introduction

Even though roundabouts comprise just a small amount of the roadway network, they generally are more complex and difficult to navigate than most other road segments. To drive in a roundabout properly and safely, the driver has to take into account the layout of the site, its geometry, and interactions with other users. Roundabout can be geometrically complex and it requires that drivers scan several different areas and keep track of several different elements to get the right information needed to perform the correct manoeuvre. So, while driving roundabouts, drivers have to perform many subtasks in an environment with many rules and complex interactions. Each task encountered by the driver at roundabout involves a sequence of: perception or recognition; decision making; execution or performance; and real time system response by the vehicle, roadway and surrounding environment. From a cognitive analysis perspective,

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the interaction between the car drivers' capabilities and the demands of the driving task determines the outcome in terms of a more or less safe driving behaviour [1].

Previous studies show that the drivers' driving behaviour at roundabout changes depending on the layout of the roundabout [2, 3]. Other studies [4, 5] modelled speed profiles at roundabouts and concluded that speed profiles differed significantly across drivers and roundabouts. A recent study shows that the stress level induced by roundabouts on drivers is more than double that induced by standard intersections [6].

The understanding of the correlations among driver behaviour and driver characteristics and road environment is very important in order to help drivers to make safe manoeuvres in increasingly complex intersections.

Many factors contribute to road safety. Some involve planning, design, construction, operation, and policing of the roadways. The most relevant factor is human factor. This includes unawareness of traffic rules and roadway condition; lack of driving skills; poor judgment; failure to interact and adjust to prevailing roadway conditions; and most importantly, aggressive driving [7].

The "incorrect" design of infrastructure (for example inappropriately designed road, wrong layout of intersections, poor positioning of pedestrian crossings, poor side distance, etc.) causes wrong driver's behaviour and other subsequent problems, i.e. a conflict situation or a traffic accident [7-9].

Previous crash investigations suggested that human error was a contributing factor to the accidents. Where human factor is cited as a contributing factor it is important to seek out where the failures occur in order to find appropriate treatments to reduce the likelihood of the same event occurring again.

This paper aims to investigate the nature and sources of unsafe driving behaviour at single-lane roundabouts using the results of driving experiment. In fact, it is believed that the possible user's unsafe behaviour could be due to critical geometric configuration of the roundabouts.

In this study, we attempt to define unsafe driving behaviour as the complex of deliberate and systematic practices that increase the risk of a conflict or crash and also investigate the types of road users and geometric characteristics of roundabouts that are directly associated with these behaviours.

These behaviours (hereinafter referred to as unsafe behaviour) represent driving activities that are often linked to crashes on the road. According to [10], these types of behaviours have the potential to degrade driving performance resulting in serious consequences for road safety and in addition greatly increase the risk of crashes.

This study has provided the favourable opportunity of observing what happens before most crashes occur. This is important because it is a proactive approach to traffic safety analysis without necessarily waiting for crashes to happen.

2 Literature review

Several researches have demonstrated the substantial contribution of roundabouts in the enhancement of safety and efficiency while comparing it with various other intersection types [11-13]. The fundamental design of roundabouts is inclusive of the geometric layout, operational as well as safety evaluation. Small changes in roundabout geometry cause significant changes in its performance related to safety and operations [14].

Despite the proven safety benefits, some crashes still occur at roundabouts. Previous studies have examined roundabouts crashes and identified major crash types and contributing factors [15,16]. Contributing factors to roundabouts crashes included entering drivers failing to yield the right-of-way to circulating vehicles, unsafe speeds, and incorrect lane choices at multilane roundabouts [17].

Alshannaq and Imam [7] found that all of the causes of roundabout crashes were related to the drivers' behaviour one way or another. Factors such as age, judgment, driving skills, attention, fatigue, experience, etc. were all found to be contributing factors to the occurrence of accidents. Similar findings have been reported in Ramisetty-Mikler et al. [18], which focused on the risky driving behaviour of Saudi Arabian adolescents. This study also highlighted factors such as young age, deficiency in training, and poor driving skills contributing to vehicle accidents. Bener et al. [19] by means of a study on driver behaviour in Qatar and Turkey demonstrated that the drivers' socio-economic conditions, driving style and skills, cultural factors, education, as well as ethnicity, contribute to traffic rule violations. Al-Rukaibi et al. [20] quantified the driver's behaviour at a roundabout. It was found that a large percent of drivers violates the traffic control devices. AL-Saleh and Bendak [21] performed another study in Al-Riyadh analysing the driver behaviour at roundabouts. They found that 90% of the chosen sample breached at least one traffic regulation. Distefano et al. [22] show that drivers adapt their driving behaviour according to their preferences on the geometric characteristics of roundabouts.

In recent times researchers have made a strong link between road safety and road user misbehaviour [8, 23-25]. For a long time, human error was most often considered as the main and more or less fatal cause of road safety problems since humans are, by nature, subject to errors.

The term human error has been used rather loosely to encompass nearly all the ways in which people can contribute to accidents through the performance of unsafe acts. Recent analyses, however, have shown that unsafe acts (i.e., potentially dangerous actions carried out in hazardous conditions) can be subdivided into two distinct classes of behaviour: errors and violations [26]. Errors have been defined in a variety of ways. In this context, an error is defined as the failure of planned actions to achieve their desired outcome without the intervention of some chance or unforeseeable agency. Violations, on the other hand, may be defined as the deliberate infringement of some regulated or socially accepted code of behaviour. Errors and violations differ both in their psychological mechanisms and in the kinds of remedial actions necessary to combat them. Errors arise as the result of information-processing problems; violations have a large motivational component [26].

Despite unsafe driving behaviours occur at all points in the road network, this may be particularly prominent at intersections, as these represent a complex part of the road system, where drivers are required to make decisions often within small timeframes. There is therefore a pressing need to examine the nature of drivers' unsafe driving behaviour at intersections, including the factors that contribute to, or mitigate these behaviours from occurring [24].

Drivers' unsafe driving behaviours are influenced by a range of personal, environmental or infrastructure factors. These factors include: inadequate knowledge, skills, training, wilful inappropriate behaviour, infrastructure and environment problems [27].

Mandiartha et al. [28], hypothesised that the geometric design and layout influence road users' behaviour. Average speeds of users were compared to test the hypothesis by using two different roundabout layouts. Although the roundabouts shared similar traffic volume, the behaviour of the users differed. The results of a study of Papantoniou et al. [29] reveal that the impact of driver characteristics and area type are the only statistically significant factors affecting the probability of driving errors. Other research found that drivers who report more experience with roundabouts also are more likely to know how to correctly navigate them, therefore driver behaviour at roundabouts has been observed to change with driver age [30-32].

Previous studies show that there is a significant need for identifying drivers who engage in unsafe driving practices, placing themselves and other road users at greater risk of involvement in a crash. This in order to design the roundabout layout such that deviant behaviour is not viable in physical terms.

3 Study methodology

3.1 Participants

Sixty-six drivers (41 males and 25 females) aged 18-65 years took part in the study. All participants held a full valid license. To vary age, they were grouped into younger drivers (18–25 years), middle-aged drivers (26–50 years) and older drivers (51-65 years). Participants' characteristics are presented in Table 1.

Table 1. Features of participants.

Category	Number	Percentage
Age		
18-25	22	33.33
26-50	26	39.39
51-65	18	27.28
Gender		
Male	41	62.12
Female	25	37.88

3.2 Test route

A 30 km urban route around the suburbs surrounding the city of Catania was used for the on-road test. The urban route was composed of two routes: test route 1, which is 16 km long and contains 9 roundabouts (roundabouts 1-9), and test route 2, which is 14 km long and contains 8 roundabouts (roundabouts 10-17). Participants made the two routes at different times to avoid that the fatigue related to the excessive length of the route could affect their driving behaviour. The roundabouts were chosen in order to have different geometric characteristics. 13 roundabouts were single-lane, while 4 roundabouts were double-lanes. Four types of manoeuvres were considered: 1st exit (i.e. the driver took the 1st exit of the roundabout); 2nd exit (i.e. the driver took the 2nd exit of the roundabout); 3rd exit (i.e. the driver took the 3rd exit of the roundabout); U-turn (i.e. the driver exit from the same leg he/she was entered). For each roundabout the drivers made at least one manoeuvre. For this study only the drivers' unsafe behaviours made on single-lane roundabouts were considered. This study regards therefore 13 roundabouts (i.e. roundabouts 1 to 10 and roundabouts 15 to 17). Figure 1 shows the two test routes and the 13 one-lane roundabouts considered for this study. Data for roundabouts 11, 12, 13 and 14 (double-lane roundabouts) will be analysed in future research.

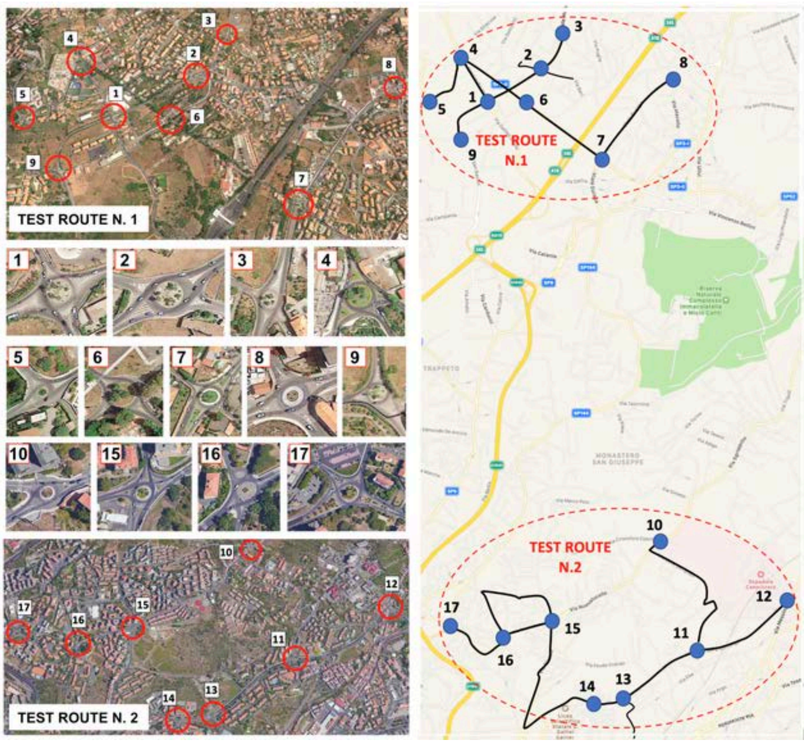


Figure 1. Details of test route 1 and 2 and of the 13 roundabouts considered for the study.

3.3 Experiment design

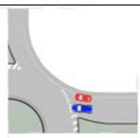
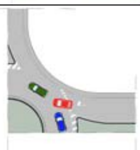
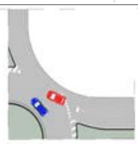
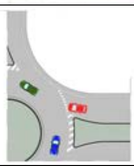
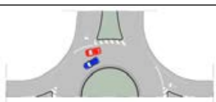
Two in-vehicle observers used a behaviour pro-forma to manually record the unsafe behaviours made during the drive. On-route, the observer located in the front passenger seat provided directions. Both observers recorded unsafe behaviours made by the driver throughout the drive, including the type, where on the route it occurred and the context in which it occurred. Upon completion of the drive, the two observers checked agreement on the unsafe behaviours recorded.

The driving experiments were conducted during off-peak hours with low traffic volume. All testing was conducted during 9:30 am and 10:30 am and 14:30 and 15:30 pm on weekdays during September and October 2019. Each participant made the test on both test route 1 and 2, in different days.

3.4 Drivers' unsafe behaviours classification

The unsafe behaviours observed during the on-road study were classified post hoc into specific types that directly reflected the nature of the behaviour made. The specific unsafe behaviours types were subdivided into three different categories: unsafe behaviours made during the approach to the roundabout (entry unsafe behaviours), unsafe behaviours made during the circulation on the roundabout (circulation unsafe behaviours) and unsafe behaviours made while exiting the roundabout (exit unsafe behaviours). Table 3 shows the drivers' unsafe behaviours types considered. Table 4 shows the number of unsafe behaviours registered during the on-road study.

Table 3. Drivers' unsafe behaviours types at single-lane roundabouts.

	Entry unsafe behaviours	
1		*High speed of approach:* Approaching the roundabout with a speed higher than the speed limits
2		*Parallel entry on entry lane:* Arranging parallel to another vehicle on the entry leg, despite the leg has one lane
3		*Selecting unsafe gap:* Selecting unsafe gap when entering the roundabout
4		*Parallel entry on circulatory roadway:* Arranging parallel to another vehicle on the circulatory roadway after entering the roundabout, despite the circulatory roadway has one lane
5		*Rejecting a safe gap:* Rejecting a safe gap when entering the roundabout
	Circulation unsafe behaviours	
6		*Parallel circulation:* Arranging parallel to another vehicle on the circulatory roadway when circulating the roundabout, despite the circulatory roadway has one lane

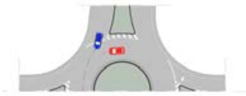
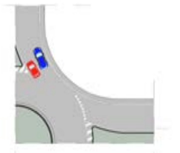
7		*Giving way:* Giving way to incoming vehicle when circulating the roundabout
8		*No circulation:* The vehicle takes the 1st exit without deviation of trajectory
	Exit unsafe behaviours	
9		*Parallel exit:* Arranging parallel to another vehicle on the exit leg
10		*Driving over the splitter island:* Driving over the splitter island when exiting the roundabout
11		*High exit speed:* Exiting the roundabout with a speed higher than the speed limits

Table 4. Number of unsafe behaviours observed.

		Number	Percentage [%]
Entry unsafe behaviours			
1	High speed of approach	1862	34.17
2	Parallel entry on entry lane	152	2.79
3	Selecting unsafe gap	759	13.93
4	Parallel entry on circulatory roadway	140	2.57
5	Rejecting a safe gap	282	5.17
Circulation unsafe behaviours			
6	Parallel circulation	455	8.35
7	Giving way	462	8.48
8	No circulation	443	8.13
Exit unsafe behaviours			
9	Parallel exit	226	4.15
10	Driving over the splitter island	576	10.57
11	High exit speed	93	1.71
Total		5450	100.00

3.5 Analytic method

In order to analyse the characteristics of the roundabouts and the characteristics of the driver that can lead to unsafe driving behaviour, the CHAID (Chi Square Automatic Interaction Detection) method was used.

CHAID method is a technique employed to discover relationships between a dependent variable and other independent variables, where a statistically significant result identifies their mutual dependence and the relationship between them. In the CHAID algorithm proposed by Kass [33], a chi-squared test (χ^2, chi-square statistic) is applied to determine the splitting condition. It is mainly used to calculate the degree of dependence between several variables–the larger the value calculated by χ^2, the higher the degree of dependence and the probability value of the variable. Moreover, a probability value is used to determine whether to continue the splitting process in the CHAID algorithm to estimate all the possible predictive variables. In this method, the significance levels of the differences between the various categories of dependent variables are tested for each variable.

Particularly, the CHAID algorithm is used to calculate attribute branches. In the CHAID branching process, each node is branched on the basis of the selected dependent variables, and the chi-squared test is used as the standard for branching. This implies that the branching is conducted whether the classification attribute is significant or not. If the branches have no significant difference, they are merged into the same branch. Conversely, if the branches differ significantly, the branch is retained and the branching process is conducted on the next layer.

CHAID analysis tries to look for patterns in datasets with multiple categorical variables and builds a model in form of a decision tree by splitting the sample or the target dependent variable. CHAID analysis is best for data with large sample size, as the predictor variables are repeatedly split to get categories with equal number of observations to get a final outcome or till CHAID analysis does not find any significantly discriminating in order to receive predictor any more. Since CHAID is best applicable in scenario for categorized value instead of continuous and clearly shows how variables best combine to explain the outcome in a given dependent variable, to outperform better than other statistical tools, such as basic kinds of regression. CHAID is convenient to use in the case of multiple variables as it offers segmentation of one variable based on the effect of combination of a range of independent variables.

In this study, the unsafe driving behaviours recorded during the driving test (as defined in Table 3) were fixed as dependent variable. Particularly, entry unsafe behaviours, circulation unsafe behaviours and exit unsafe behaviours were considered separately. The independent variables considered are instead the drivers' characteristics, the roundabout characteristics and the manoeuvres showed in Table 5.

Table 5. CHAID analysis independent variables.

	Variable	Categories
Driver's characteristics	Gender	Male Female
	Age	18-25 26-50 51-65
Roundabout characteristics	Roundabout Radius (RR)	<14m 14-20 m >20m
	Circulatory roadway width (CW)	<6m 6-8m >8m
	Entry width (EnW)	<4m 4-6m >6m
	Exit width (ExW)	<4m 4-6m >6m
	Entry radius (EnR)	<10m 10-30m 31-50m >50m
	Exit radius (ExR)	<10m 10-30m 31-50m >50m
	Splitter island	Painted Raised
Manoeuvre	Manoeuvre made	1st exit 2nd exit 3rd exit U-turn

3.6 Results and discussions

The CHAID analysis was applied separately for entry, circulation and exit unsafe behaviours. For each type of unsafe behaviour, a tree diagram was obtained.

Figure 2 shows the tree diagram obtained for entry unsafe behaviours. The dependent variable considered is entry unsafe behaviour, which can assume values from 1 to 5 (see Table 3). The independent variables considered are the ten variables shown in Table 4. All entry unsafe behaviours are divided into 22 subgroups from root node to leaf nodes through different branches. Seven variables out of the original set of ten provide a significant explanation of the entry unsafe behaviours. The tree structure involves therefore seven splitting variables: manoeuvre (chi-square = 126.613; *p-value* = 0.000), entry radius (chi-square = 29.183; *p-value* = 0.000; chi-square = 90.515; *p-value* = 0.000), roundabout radius (chi-square = 49.447; *p-value* = 0.000), gender (chi-square

= 13.262; *p-value* = 0.010), entry width (chi-square = 58.892; *p-value* = 0.000), splitter island (chi square = 29.719; p-value = 0.000; chi-square = 12.629; *p-value* = 0.013) and circulatory roadway width (chi square = 18.059; p-value = 0.001) meaning that the variable entry radius is responsible for two partitions and the variable splitter island is responsible for two partitions. The manoeuvre is therefore the variable with the most significant effect on entry unsafe behaviours. Among the roundabout characteristics, the entry radius and the roundabout radius are the variables with the most significant effect on entry unsafe behaviours. Among the driver's characteristics, only the gender has a significant effect on entry unsafe behaviours.

From the analysis of Figure 2 it can be observed that the most frequent entry unsafe behaviour is unsafe behaviour 1 (i.e. *High speed of approach*). The percentage of unsafe behaviour 1 at node 0 is 58.3%. Unsafe behaviour 3 (i.e. *Selecting unsafe gap*) is very frequent too. The percentage of unsafe behaviour 3 at node 0 is 23.8%.

The seven splitting variables lead to the tree being divided into three levels. The first optimal split in node 0 is according to manoeuvre, which classifies entry unsafe behaviours into three groups: the tree shows respectively 27.4% of unsafe behaviours for 1st exit manoeuvres, 61.1% of unsafe behaviours 2nd and 3rd exit manoeuvres overall and 11.6% of unsafe behaviours for U-turn manoeuvres.

Unsafe behaviour 1 (i.e. *High speed of approach*) for U-turn manoeuvres is the unsafe behaviour with the highest percentage of the first level of the tree (70%). The distribution of unsafe behaviour 1 is similar for 1st and 2nd exit manoeuvres (respectively 52.7% and 58.5%). On the other hand, it is interesting to note that the distributions of the other unsafe behaviours change according to the exit that the driver has to take. Unsafe behaviour 4 (i.e. *Parallel entry on circulatory roadway*) is significantly major for 1st exit manoeuvres (9.6%) rather than for 2nd and 3rd exit manoeuvres (2.7%) and for U-turn (0.8%). This suggests that the drivers who take the 1st exit are led to believe that they do not interfere with circulating vehicles. This conclusion is supported by the low percentage of unsafe behaviour 5 (i.e. *Rejecting a safe gap*) for 1st exit manoeuvre (5.8%). In the second level of the tree, the group including 1st exit leads to another split based on entry radius; the group including 2nd and 3rd exit leads to another split based on entry radius too; while the group including U-turn leads to another split based on the roundabout radius. It is noteworthy that unsafe behaviour 1 (i.e. *High speed of approach*) is much more evident on roundabout with smaller diameter (respectively 83.1% for RR<14m, 68.9% for 14m≤RR≤20m and 52.0% for RR>20m). Conversely, unsafe behaviour 3 (i.e. *Selecting unsafe gap*) and unsafe behaviour 5 (i.e. *Rejecting a safe gap*) are more frequent for roundabouts with bigger diameter. In the third level of the tree, the gender segments the group including 1st exit manoeuvre and EnR>50m or 10m≤EnR≤30m or EnR<10m into two subgroups. The leaf nodes 13 and 14 shows that for these conditions, men made more entry unsafe behaviours than women. For the groups 2nd/3rd exit manoeuvre, in case of big entry radius (30m≤EnR≤50m and EnR>50m), the splitter island has a significant effect. While for medium or small entry radius (10m≤EnR≤30m and EnR<10m) the entry width and the circulatory roadway width have, respectively, a significant effect. It can be observed that for 2nd/3rd exit manoeuvre, small Entry Radius (EnR<10m) and narrow circulatory roadway (CW<6m) the number of entry unsafe behaviours made is the minimum (1.9%).

For 2nd and 3rd exit manoeuvres, when small entry radius (En<30m) are paired with small entry width (EnW<6m) or with big circulatory roadway width (6m≤CW≤8m), the number of unsafe behaviour 1 (i.e. *High speed of approach*) is greatly increased. The driver's characteristics does not seem to strongly affect entry unsafe behaviours. However, the gender has a certain influence on unsafe behaviour 3 (i.e. *Selecting unsafe gap*) for 1st exit manoeuvres. It seems indeed that in these cases men are more inclined than women to select unsafe gap (unsafe behaviour 3, respectively 26.6% for men and 18.6% for women). On the other hand, women are more likely to reject a safe gap (unsafe behaviour 5, respectively 11.3% for woman and 5.0% for men).

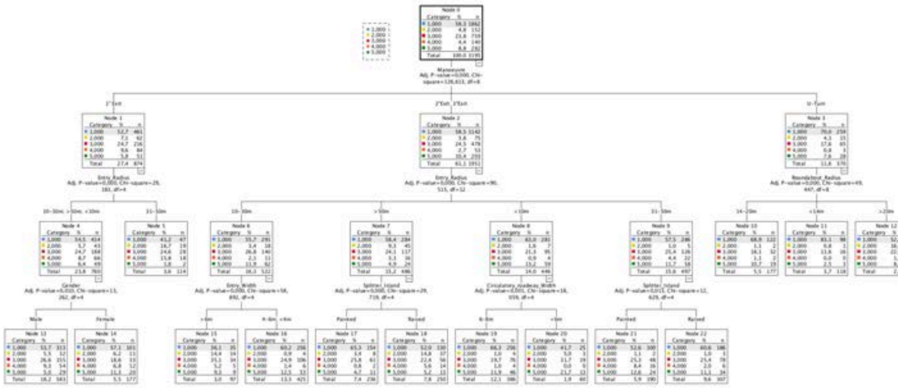


Figure 2. Tree diagram obtained from CHAID analysis for entry unsafe behaviours.

Figure 3 shows the tree diagram obtained for circulation unsafe behaviours. The dependent variable considered is circulation unsafe behaviour, which can assume values from 6 to 8 (see Table 3). The independent variables considered are the ten variables shown in Table 4. All circulation unsafe behaviours are divided into 16 subgroups from root node to leaf nodes through different branches. Six variables out of the original set of ten provides a significant explanation of the circulation unsafe behaviours. The tree structure involves therefore six splitting variables: manoeuvre (chi-square = 1119.384; *p-value* = 0.000), exit radius (chi-square = 14.683; *p-value* = 0.001), entry width (chi-square = 13.265; *p-value* = 0.001), roundabout radius (chi-square = 11.931; *p-value* = 0.002), gender (chi-square = 7.615; *p-value* = 0.006) and exit width (chi square = 11.025; p-value = 0.003; chi square = 9.041; p-value = 0.008) meaning that the variable exit width is responsible for two partitions. The manoeuvre is therefore the variable with the most significant effect on circulation unsafe behaviours. Among the roundabout characteristics, the exit radius, the entry width and the roundabout radius are the variables with the most significant effect on circulation unsafe behaviours. Among the driver's characteristics, only the gender has a significant effect on circulation unsafe behaviours.

From the analysis of Figure 3 it can be observed that there is no a circulation unsafe behaviour more frequent than the others. The percentages of unsafe behaviours 6, 7 and 8 at node 0 are indeed comparable (33.5%, 34.0% and 32.6% respectively).

The six splitting variables lead to the tree being divided into three levels. The first optimal split in node 0 is according to manoeuvre, which classifies circulation unsafe behaviours into four groups: the tree shows respectively 41.9% of unsafe behaviours for 1st exit manoeuvre, 18.8% of unsafe behaviours for 2nd exit manoeuvre, 27.5% of unsafe behaviours for t 3rd exit manoeuvre and 11.8% of unsafe behaviours for U-turn manoeuvre. The majority of circulation unsafe behaviours are therefore made for 1st exit manoeuvres. It has to be noted that unsafe behaviour 8 (i.e. *No circulation*) can be made only for 1st exit manoeuvres. This is the reason why the percentage of unsafe behaviour 8 is 0.0% at nodes 2, 3 and 4. In the same way, unsafe behaviour 7 (i.e. *Giving way*) can be made only for 2nd, 3rd and U-turn manoeuvres. For this reason, the percentage of unsafe behaviour 7 at node 1 is 0.0%. Moreover, it is interesting to observe that the percentage of unsafe behaviour 7 gradually increases for 2nd exit, 3rd exit and U-turn manoeuvres (respectively 35.3%, 65.0% and 80.1%). This leads to the conclusion that the percentage of unsafe behaviour 7 increases with the number of legs that the driver encounters before exiting the roundabout. For 2nd exit manoeuvre unsafe behaviour 6 (i.e. *Parallel circulation*) is the most common (64.7%), while unsafe behaviour 7 (i.e. *Giving way*) is less frequent (35.3%). For 3rd exit manoeuvres the distribution is the opposite, i.e. unsafe behaviour 7 (i.e. *Giving way*) is the most common (65.0%), while unsafe behaviour 6 (i.e. *Parallel circulation*) is less frequent (35.0%). Both manoeuvres are characterized by long trajectories, but during 2nd exit manoeuvres the driver encounters only one leg before exiting the roundabout. Because of these unsafe behaviours 7 are less frequent for 2nd exit manoeuvres. On the other hand, during 3rd exit manoeuvres the driver encounters two legs before exiting the roundabout. This is why unsafe behaviour 7 are more frequent for 3rd exit manoeuvres.

In the second level of the tree, the group including 1st exit leads to another split based on exit radius. It can be observed that the majority of unsafe behaviours is made for big exit radius (i.e. ExR>30m). The group including 3rd exit leads to another split based on entry width, even if the percentages of unsafe behaviours obtained for the two categories of entry width are comparable (respectively 13.9% and 13.6%). However, it is noteworthy that the percentage of unsafe behaviour 7 (i.e. *Giving way*) for 4m≤EnW≤6m (74.1%) is the highest. The group including U-turn leads to another split based on the roundabout radius. It is interesting to observe that for U-turn manoeuvres the percentage of unsafe behaviour 6 (i.e. *Parallel circulation*) is very small (3.9%) for small radius of roundabout (RR<14m), while is definitely higher (27.3%) for bigger radius of roundabout (RR>14m). This suggests that the U-Turn manoeuvre on a circulatory roadway with small radius is constrained and makes it very difficult to arrange on parallel lines.

In the third level of the tree, the gender segments the group including 1st exit manoeuvre and ExR>50m or 10m≤ExR≤30m into two subgroups. Male drivers made more circulation unsafe behaviours than female drivers. Men made 67.1% of unsafe behaviour 8 and 32.9% of unsafe behaviour 6, while women made more unsafe behaviour 8 (90.2%).

The exit width segments into two subgroups both the group including 1st exit manoeuvre and 30m≤ExR≤50m and the group including 3rd exit manoeuvre and 4m≤EnW≤m. It is noteworthy the influence of entry width for 3rd exit manoeuvre: the percentage of circulation unsafe behaviours for 4m≤EnW≤6m (8.7%) is almost double than the percentage for EnW<4m (4.9%).

Figure 4 shows the tree diagram obtained for exit unsafe behaviours. The dependent variable considered is exit unsafe behaviour, which can assume values from 9 to 11 (see

Table 3). The independent variables considered are the ten variables shown in Table 4. All exit unsafe behaviours are divided into 13 subgroups from root node to leaf nodes through different branches. Four variables out of the original set of ten provides a significant explanation of the exit unsafe behaviours. The tree structure involves therefore four splitting variables: manoeuvre (chi-square = 114.558; *p-value* = 0.000); exit width (chi-square = 58.953; *p-value* = 0.000), splitter island (chi-square = 27.320; *p-value* = 0.000, chi-square = 45.671; *p-value* = 0.000) and exit radius (chi-square = 10.960; *p-value* = 0.013) meaning that the variable splitter island is responsible for two partitions. The manoeuvre is therefore the variable with the most significant effect on exit unsafe behaviours. Among the driver's characteristics, no variables have a significant effect on exit unsafe behaviours.

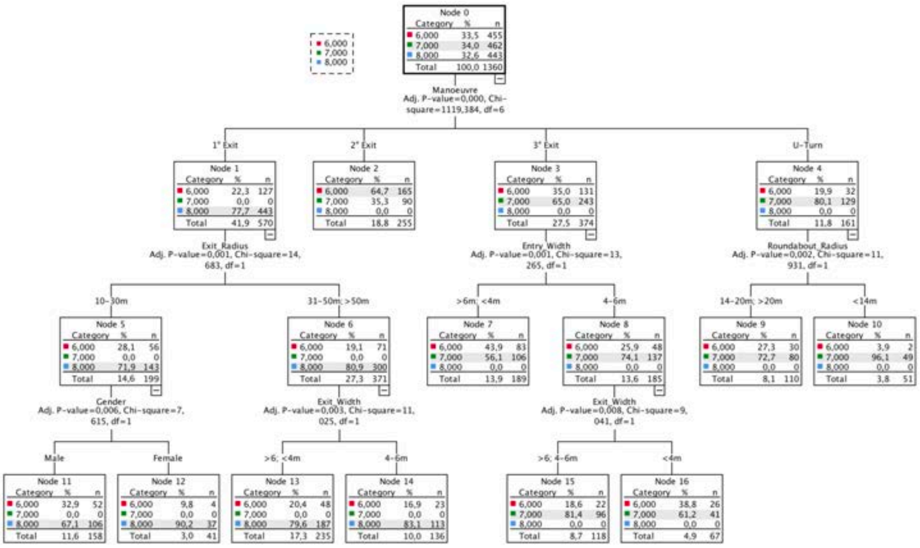


Figure 3. Tree diagram obtained from CHAID analysis for circulation unsafe behaviours.

From the analysis of Figure 4 it can be observed that unsafe behaviour 11 (i.e. *High exit speed*) is the most frequent. The percentage of unsafe behaviour 11 at node 0 is indeed 64.4%. This is a confirmation of the results obtained for entry unsafe behaviour. Drivers are indeed led to try to make the manoeuvres on roundabouts as fast as possible. This leads to aggressive behaviours, which are evident on exit unsafe behaviours too. 65% of exit unsafe behaviours regards indeed *High exit speed* (i.e. unsafe behaviour 11) and about 25% regards *Driving over the splitter island* (i.e. unsafe behaviours 10).

The four splitting variables lead to the tree being divided into three levels. The first optimal split in node 0 is according to manoeuvre, which classifies exit unsafe behaviours into four groups: the tree shows 34.6% of unsafe behaviours for 2nd exit manoeuvre, 24.6% of unsafe behaviours for 1st exit manoeuvre, 26.1% of unsafe behaviours for 3rd exit manoeuvre and 14.6% U-turn. The majority of exit unsafe behaviours are therefore made for 2nd exit manoeuvre. It is interesting to observe that the percentage of unsafe behaviour 11 (i.e. *High exit speed*) for U-turn manoeuvre is the highest (93.9%).

For 1st and 3rd exit manoeuvres unsafe behaviour 11, despite being prevalent, it is comparable to other unsafe behaviours. About 40% of unsafe behaviours for 3rd exit manoeuvres regards *Driving over the splitter island* (i.e. unsafe behaviours 10). For 1st exit manoeuvres the percentage of unsafe behaviour 11 is particularly high (28.6%) and the percentage of unsafe behaviour 9 (i.e. *Parallel exit*) is relevant too (21.4%). The results suggest therefore that when drivers take the 1st exit they tend to make a direct and fast manoeuvre without significant changes in the turning radius; this often results in driving over the splitter islands and in arranging parallel to other vehicles on the exit leg. On the other hand, when the drivers take the 3rd exit the trajectories lead much more rarely to arrange parallel to other vehicles on the exit leg, even if they often lead to drive over the splitter islands (principally for painted island).

In the second level of the tree the exit width segments into two subgroups the group including 2nd exit manoeuvre. In case of ExW>6m the percentage of unsafe behaviour 11 (i.e. *High exit speed*) is very high (96.7%), while it is smaller for ExW<4m (48.7%). The group including 1st exit manoeuvre leads to another split based on splitter island. It can be observed that the percentage of exit unsafe behaviours is major for painted splitter islands (16.9%) rather than for raised splitter island (7.7%). In the third level of the tree, the splitter island segments the group including 2nd exit manoeuvre and 4m≤ExW≤6m into two subgroups. The exit radius segments the group including 1st exit manoeuvre and painted splitter island into two subgroups.

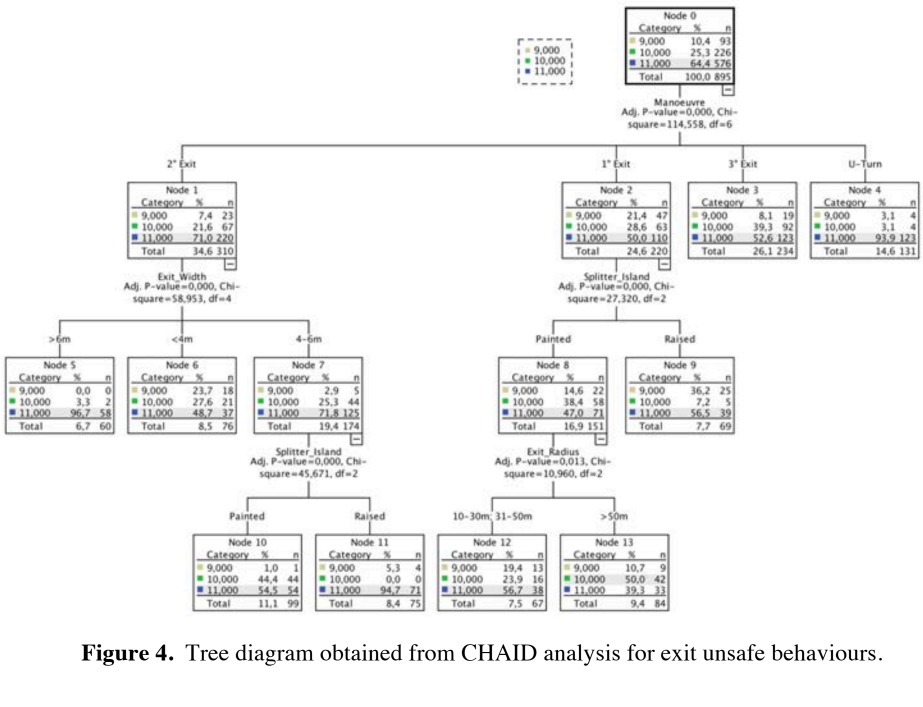


Figure 4. Tree diagram obtained from CHAID analysis for exit unsafe behaviours.

4 Conclusions

Proper road design is crucial to prevent unsafe driving behaviours in traffic and less unsafe behaviours would result in fewer accidents. This paper aimed to identify the contributing factors affecting the drivers' unsafe behaviours at single-lane roundabouts. Unsafe behaviours are evaluated based on the behaviour of sixty-six drivers who performed an on-road test around the suburbs surrounding the city of Catania. Three CHAID analysis were developed in order to analyse the influence of driver's characteristics, roundabout characteristics and manoeuvre on entry, circulation and exit unsafe behaviours respectively.

The results of this study show that the manoeuver that the driver have to perform in the roundabout is the variable that most influences unsafe driving behaviours, both when entering, circulating and exiting. The unsafe behaviours observed more frequently are the high speed with which the drivers travel the roundabout and the lack of deflection in the execution of the right turn manoeuver (1^{st} Exit).

Furthermore, the study found that the roundabout characteristics (lanes width, radii, splitter islands) influence unsafe driving behaviours at roundabouts. In particular: 1) the entry radius and the roundabout radius are the variables with the most significant effect on entry unsafe behaviours; 2) the majority of circulation unsafe behaviours are made for big exit radius (over 30 meters); 3) the exit width is the geometric variable with the most significant effect on exit unsafe behaviours, mainly causing high exit speed especially in the execution of the crossing manoeuvre. On the other hand, among the driver's characteristics (gender, age and mean of transport) only the gender was found to be significant (with low significance).

The results of this study contribute to increase knowledge about the relationship between road design and human behaviour in order to encourage the design of the physical road layout in such a way that incorrect driving behaviour is not viable in physical terms. The main message is that the human factor both in terms of behaviour and physical vulnerability is the main problem in transport safety. Therefore, it is necessary to optimize the design criteria and, at the same time, to take a series of technical and organizational actions to neutralise the human factor to achieve safety of the transportation infrastructures.

These findings provide the foundation for further research and will be used in further research to develop improved models that explicitly account for the different unsafe types of behaviour in other roundabout configurations. To expand the data presented here, future work should also seek to address the nature of similar types of behaviour occurring at multilane roundabouts and turbo roundabouts. Precisely the turbo roundabouts, through the organization of the lanes of the circulatory roadway that forces the vehicles to move within obligatory paths, could represent the tool to heavily influence the behaviours of the drivers, to the benefit of road safety performance.

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