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Analysis of Pedestrian Crossing Behaviour at Roundabout

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Abstract

Studies looking at roundabout safety have generally focused on drivers, overlooking the importance of the safety of vulnerable users such as pedestrians. Crosswalks at roundabouts are useful for pedestrians and increase safety. They should be placed to attract the maximum number of pedestrians, who would otherwise cross the road haphazardly. In this study, we analyse the street crossing behaviour of non-elderly and elderly pedestrians by filming their crossing behaviour with video cameras at 4 selected roundabouts. Data on pedestrian behaviour, including kerb delay and crossing conditions (legal and illegal), are then extracted and analysed.

The crosswalks studied were intentionally chosen with different setback distances, to understand pedestrians' willingness to deviate from the linear path when there are no bollards or other devices forcing them to cross on the crosswalk. Most of the pedestrians observed did not stop to wait for a passing vehicle but they continued to walk "zigzagging" among cars. The CHAID (Chi-square Automatic Interaction Detector) decision tree was used to identify the significant factors leading to increased likelihood of illegal crossing and highest kerb delay values. Path analysis was used to test the direct effect of independent variables on dependent variables.

For Crossing condition, CHAID analysis results showed that the more significant variables were: type of street (main or secondary), type of pedestrian (non-elderly; elderly), and distance of intersection from roundabout. While the analysis of PATH shows a direct relationship between illegal crossings and secondary streets and a negative relationship with Crosswalk length. For kerb delay, the results of the CHAID analysis showed that there was only one significant variable: type of pedestrian. While the PATH analysis highlighted that elderly pedestrians were strong directly associated with higher Kerb delay values and that also secondary streets were directly associated with higher kerb delay.

This study can help researchers and practitioners understand pedestrian crossing behaviour at roundabouts, both to develop pedestrian delay models and to define measures to improve pedestrian safety.

Keywords: Pedestrians safety; Crossing conditions; Kerb delay; Chi-square Automatic Interaction Detector Analysis; Path Analysis.

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1. Introduction

In order to increase the safety and functionality of road traffic and reduce speed, roundabouts are often built in urban areas as well (Šurdonja et al., 2012, Hydén and Várhelyi, 2000). Studies related to roundabout safety have generally focused on drivers, overlooking the importance of the safety of vulnerable road users, such as pedestrians and cyclists (Distefano et al., 2019; Leonardi et al., 2019; Perdomo et al., 2014). In urban areas, pedestrians must cross at intersections, and crosswalks are often present near entry/exit approaches of roundabouts. Urban structure plays a key role in providing available paths for pedestrian flows through urban areas. Improving accessibility between traffic intersections and the destination must include the design of urban facilities. Crosswalks at roundabouts should be appropriately placed to both attract the maximum number of pedestrians who would otherwise cross the road haphazardly and give drivers enough time to stop safely (Sisiopiku and Akin, 2003 Cohen et al., 2013). Crossing the road can be seen as a challenging and demanding task, as it requires several processes, decisions and actions to be carried out quickly and sometimes in parallel. The act of crossing the road requires pedestrians to trade off saving time against the likelihood of a collision. The proper design of urban spaces must consider all age groups and issues related not only to safety but also to perception and comfortable movement. Intersections in urban areas are not always designed with the needs of pedestrians in mind, but are often designed for motor vehicles, which can lead to long waits for pedestrians, resulting in unsafe maneuvers. More attention should be paid to pedestrian safety, as the number of casualties among people crossing an intersection is steadily increasing year by year (Soathong et al., 2019; Xu et al., 2019; Olszewski et al., 2015). A good understanding of pedestrian crossing behaviour under mixed traffic conditions is necessary to provide the adequate infrastructure and also to improve pedestrian safety, especially at intersections. Recent studies have shown the importance of proper design of pedestrian crossings at intersections (Tang et al., 2020; Zhuang and Wu, 2011). Analysing of pedestrian crossing behaviour in urban areas can help understand the way pedestrians interact with the street and the traffic environment. It can also help to understand how they balance the need for comfort and safety at the expense of delay within existing traffic rules. Several studies have been conducted to analyse pedestrian crossing behaviour at signalized intersections (Pratelli et al., 2019; Koh, et al., 2014) and at unsignalized intersections (Jain et l., 2014; Sahani et al, 2018). The literature shows that pedestrian crossing behaviour is influenced by socioeconomic factors (Marisamynathan and Vedagiri, 2018; Tom et al., 2011) (e.g., age, gender), traffic characteristics (Asaithambi et al., 2016) (e.g., speed and traffic flow), the street environment (Pratelli et al., 2019) (e.g. urban context, crossing walking distance, presence of crossing facilities), and subjective factors (Papadimitriou et al., 2017) (e.g., risk perceptions, walking motivation). There are many studies on exploring the behaviours of pedestrians crossing the road at signalized and unsignalized intersections, indeed the literature analysing pedestrian behaviour at roundabouts is still scarce (Perdomo et al., 2014). Therefore, there is a need for comprehensive studies that identify the factors that may influence pedestrians crossing behaviour at roundabout.

This study investigated the behaviour of both older and younger adult pedestrians when crossing the road at a leg of roundabout. Road crossing behaviour was analysed using unobtrusive video footage of road crossings for a sample of younger and older pedestrians at four urban roundabouts. An initial analysis of the number of legal/illegal crossings was developed to understand what factors encourage pedestrians to cross illegally. Then, for the legal crossings, the video footage was processed to calculate a parameter named kerb delay, which is the time interval between the moment when the rear of the last vehicle in the queue overtakes the pedestrian waiting to cross and the moment when the pedestrian takes the first step to cross. The data obtained from the videos were analysed accordingly to define the influence of some parameters on them.

2. Methodology

2.1. Study locations

Observations were made on 4 pedestrian crosswalks placed on the legs of two urban roundabouts located in the Metropolitan Area of Catania. There were no refuge islands at any of the legs of the roundabouts studied.

For each crossing pedestrian, the following characteristics were recorded: the crosswalk distance from the roundabout (which was calculated from the circulatory roadway), the length of the crosswalk and the type of street on which it is located. The sites studied were specifically chosen in order to have different characteristics from each other, to evaluate the influence of these characteristics on pedestrian crossing behaviour. Table 1 shows the characteristics of each crossing pedestrian.

Table 1. Characteristics of the crosswalks studied.

Pedestrian crosswalk	Crosswalk distance (m)	Crosswalk length (m)	Street
1	10-15	>10	Secondary
2	>15	>10	Main
3	10-15	<10	Secondary
4	<10	>10	Main

2.2. Video data collection

Two synchronized cameras were used to record the natural scene at the sites. A car parked near the crosswalk on the side of the road was set up with two video cameras positioned to provide images of both oncoming traffic and crossing pedestrians. The cameras were hidden into the car so that pedestrians could not see them. Filming occurred without pedestrian’s knowledge to overcome possible changes in behaviour. Video recordings were made for a total of 32 (8x4) hours. The video recordings were made between 10:30 a.m. and 12:30 a.m. and between 3:30 and 5:30 p.m. on weekdays for eight days in September 2020. The hourly intervals of the video recordings were chosen so that the vehicle flows and the approaching speeds were comparable on all legs of the roundabouts. A random and concurrent selection of participants was used, that is, as they entered the site without any selection bias. The video was played in Adobe Premiere Pro CS4 version 4.0.1 to perform a frame-by-frame analysis.

2.3. Indicators to describe crossing behaviour

In order to analyse pedestrians crossing behaviour at roundabout, two variables were considered: the crossing condition (legal or illegal) and the kerb delay.

Often, the crosswalk setback results in a deviation from the linear path that pedestrians are led to follow spontaneously. In fact, people naturally hope to reach their destination quickly, so they are unlikely to detour. In a roundabout, this deviation is even more significant. The four crosswalks studied were intentionally chosen with different distances from the circulatory roadway, in order to understand pedestrians' willingness to deviate from the linear path when there are no bollards or other obstacles forcing them to cross on the crosswalk. If a pedestrian does not cross at the crosswalk, the crossing is considered illegal. The number of illegal/legal crossings was calculated for all observed crossing pedestrians.

The kerb delay was the time from the last vehicle passing a waiting pedestrian to the pedestrian's first step onto the roadway (Oxley et al., 1997). The kerb delay was calculated only for pedestrians who stopped before deciding to cross after a vehicle had passed their crossing line. The kerb delay allows to determine, respectively, the delay (positive value) or the anticipation (negative value) of the pedestrian in crossing with respect to the incoming vehicle. The delay occurs when, after the vehicle passes, leaving the space free for the pedestrian to cross, the pedestrian hesitates to cross immediately. The anticipation occurs when the pedestrian, from a static position, starts to cross before the incoming vehicle has left the free space behind it to allow the pedestrian to cross. Based on the videos, it was possible to classify the pedestrians into two categories: elderly and non-elderly pedestrians. In order to analyse the crossing conditions, for each pedestrian crosswalk, the crossing pedestrians were detected so as to have 80 movements for non-elderly pedestrians and 80 for elderly pedestrians. These were classified into legal and illegal crossings.

Instead, to study kerb delay, since most of the observed pedestrians did not stop to wait for a passing vehicle but, although slowing down, continued to "zigzag" between cars, only 40 pedestrians (20 elderly pedestrians and 20 non-elderly pedestrians) were recorded to define the kerb delay.

2.4. Analytical Methods

The data obtained from the video analysis were treated to determine the distribution of the parameters chosen to define the crossing behaviours (crossing condition and kerb delay) according to the defined aspects (crosswalk distance, crosswalk length and street) and to evaluate the influence of these aspects on these parameters.

To achieve the first objective, CHAID (Chi-square Automatic Interaction Detector) analysis was used, while path analysis was used for the second objective. CHAID analysis is a database segmentation technique that is able to extract significant information from a large amount of data. After a test sequence, the data is divided into CHAID using a statistical algorithm. The original node on the independent variable is split into as many subsets as possible. The process then splits these new nodes according to the variables that distinguish each of them. This process continues until no more splits are significant. 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. To identify optimal splits, the Chi-Square Independence Test is used to examine and test the cross-tabulations between each input variable (i.e., independent variables) and the outcome variables (i.e., dependent variable).

Path analysis is a statistical technique used primarily to examine the comparative strength of direct and indirect relationships between variables. A set of parameters is estimated by solving one or more structural equations to test the fit of the correlation matrix between two or more causal models that the researcher assumes fit the data (Lleras, 2005). Because path analysis assesses the comparative strength of different effects on an outcome, the relationships between variables in the path model are expressed in terms of correlations and represent the hypotheses proposed by the researcher. Exogenous variables are variables whose cause is external to the model and whose role is to explain other variables. Endogenous variables are variables that are caused by one or more variables within the model. The single straight arrows indicate a causal relationship leading from the explanatory (causal) variable to the outcome variable (effect). The curved double arrows indicate that the two variables might be related, but the model makes no prediction about the direction of the relationship. Path models often report the standardized regression coefficients (beta). Standardized coefficients allow researchers to compare the relative size of the effects of different explanatory variables in the path model by adjusting the standard deviations so that all variables have equal standard deviations despite having different units of measurement. These standardized path coefficients measure the relative strength and sign of the effect from a causal variable to an endogenous one. Table 2 shows the variables used in both analyses.

Table 2. Variables used in analytical methods.

Variable	**Variable type**	**Categories**
Crossing Condition	Dependent Variable	0=legal 1=illegal
Kerb delay	Dependent Variable	A=< -1s B= -1s ÷ -0.5s C= -0.5s ÷ 0s D= 0 s÷ 0.5s E= 0.5s ÷ 1s F= >1s
Pedestrian	Independent Variable	0=Non-elderly 1=Elderly

Crosswalk distance	Independent Variable	0=<10m 1= 10 m ÷ 15m 2=>15m
Crosswalk length	Independent Variable	0=<8m 1=8m ÷ 10m 2=>10m
Street	Independent Variable	0=Main 1=Secondary

3. Results and discussion

3.1. Crossing condition

Figure 1 shows the tree diagram obtained for the CHAID analysis of Crossing condition.

The “Crossing condition” is divided into 12 subgroups by various branches connecting the root node to the leaf nodes. The splitting variables lead to the tree being divided into three levels. The structure of the tree foresees the type of street as the first (and therefore most significant) dividing variable.

From the analysis of Figure 1 it can be observed that the most frequent crossing condition is legal crossing. The percentage of legal condition at node 0 is indeed 69.4%. This percentage increases in correspondence with the main street; the percentage of legal crossings on main streets is 80.6% (node 2) against 58.1% on secondary streets (node 1). This indicates that users perceive a greater level of risk on main streets, probably due to major interactions with vehicles.

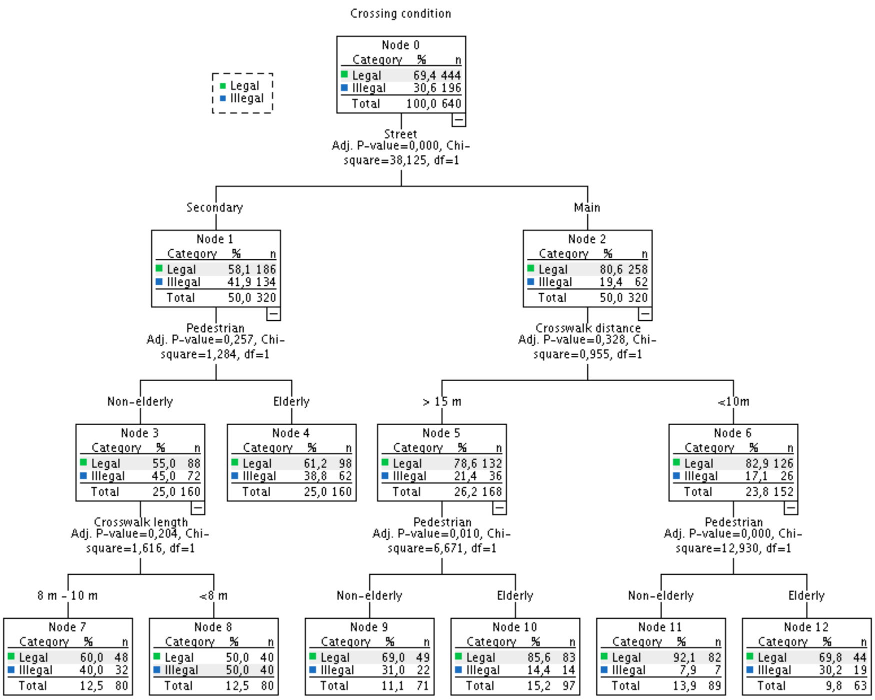

Fig. 1. Crossing condition CHAID tree diagram.

The third level of the tree shows that the crosswalk length is significant only for non-elderly pedestrians on secondary streets, where legal crossings are major for longer crosswalks.

The type of pedestrian influences crossings at various distances on main streets, legal crossings are greater for non-elderly for short distances from the roundabout, while for greater distances elderly pedestrians show more legal crossings. This seems to suggest that the younger users do not accept too long routes at the expenses of safety; on the other hand, the elderly accept longer routes, preferring greater safety.

The path analysis was carried out in order to assess the strength of the links among exogenous and endogenous variables. According to the magnitude of direct effects, shown in the diagram of figure 2, the variables that most influence illegal pedestrian crossings are (in decreasing order of importance): type of street (0.16), Crosswalk length (-0.09), Crosswalk distance (0.04), and type of pedestrian (-0.02). The type of street and Crosswalk distance were found to be positively correlated with the Crossing conditions. In contrast, Crosswalk length and type of pedestrian were inversely related to Crossing conditions. It can be seen that none of the exogenous variables strongly influence the condition of legal / illegal crossings. The Path analysis result indicates that almost all the exogenous variables had indirect effects on these correlations in the model. Among these interactions, the combination of type of street and crosswalk length had the largest impact of interaction (−0.90) on crossing condition, and the negative interaction indicated that there was a mutually restricted relationship between these two factors. There was also another one good interactions, the one between type of pedestrian and crosswalk distance (0.11), and the positive interaction indicated that there was a mutually relationship between these two factors.

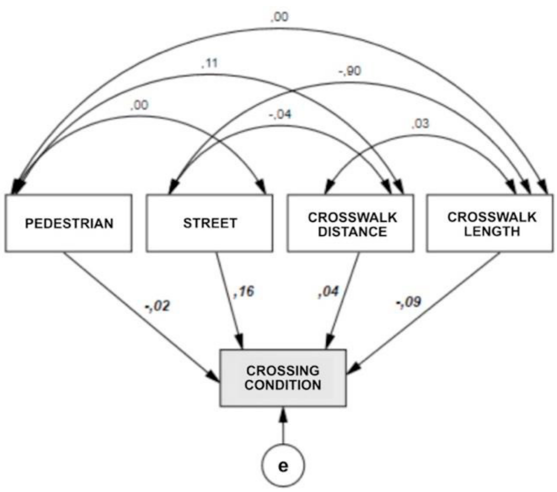

Fig. 2. Crossing condition diagram of path analysis.

3.2. Kerb Delay

Figure 3 shows the tree diagram obtained for the CHAID analysis of Kerb Delay.

The “Kerb Delay” is divided into only 2 subgroups by various branches connecting the root node to the leaf nodes. The splitting variables lead to the tree being divided into one level. The structure of the tree foresees the type of pedestrian as the only significant variable. From the analysis of Figure 3 it can be observed that the most frequent Kerb Delay is B (i.e. -1s ÷ -0.5s). The percentage of negative values of Kerb Delay is 82.4% (A+B+C). This means that pedestrians tend to get off the sidewalk before the vehicle has entirely passed. This percentage increases for non-elderly pedestrians, it is equal to 98,70% (node 1); instead, this percentage for elderly pedestrians is 66,20% (node 2). This result also confirms the more aggressive behaviour of non-elderly pedestrians. For the definition of the kerb delay no other variable, among those considered, was significant.

Also in this case the path analysis was developed in order to evaluate the strength of the links among exogenous and endogenous variables. According to the magnitude of direct effects, shown in the diagram of figure 4, the variables that most influence the Kerb Delay (in decreasing order of importance) are: type of pedestrian (0.51), type of street (0.31), Crosswalk length (0.22), and Crosswalk distance (0.09).

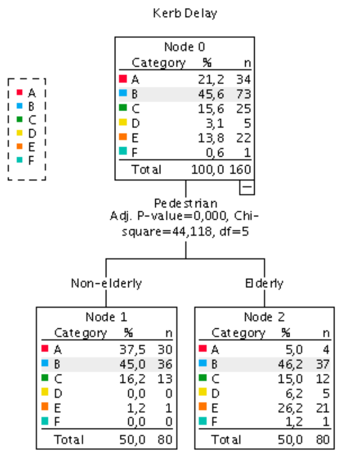

Fig. 3. Kerb Delay CHAID tree diagram.

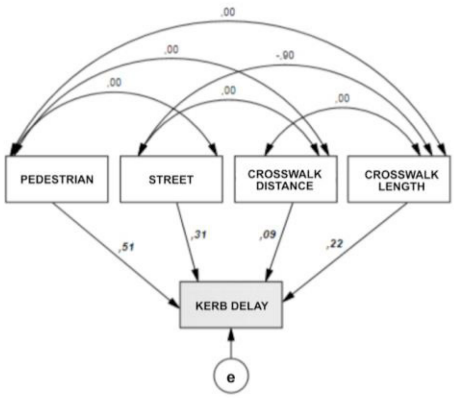

Fig. 4. Kerb Delay diagram of path analysis.

All exogenous variables were found to be positively correlated with the Kerb Delay. It can be seen that only one out of four variables (Pedestrian) have a strong influence on the values assumed by the Kerb delay. While, two other variables (Street and Crossing length) have a less strong link and the Crossing distance variable has a very weak link with the values assumed by the Kerb delay. In particular, it is evident that the propensity to delay the start of the crossing manoeuvre is a prerogative of elderly pedestrians on secondary streets and for long crosswalks. The Path analysis result indicates that almost all the exogenous variables did not have indirect effects on these correlations in the model. Only the combination of type of street and crosswalk length had the largest impact of interaction (−0.90) on Kerb Delay.

4. Conclusions

The most interesting result of this study is that the behaviour of pedestrians seems to be strongly influenced by human factors related to age, rather than by the location of crosswalks on the legs of roundabouts. The desire of non-elderly pedestrians to move quickly results both in their tendency not to use crosswalks when they are at some distance from the roundabout, and in their tendency to make their first step forward to cross the road immediately before the back of the last vehicle passed. On the other hand, elderly pedestrians are overall more respectful of the rules and approach the crossing of a roundabout leg with greater caution, as they perceive this manoeuvre as dangerous. The authors intend to get deeper in this study by relating the indicators describing crossing behaviour at roundabout to pedestrian and vehicular speeds, in order to evaluate also the parameters associated with user safety.

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