Analysis of drivers' errors at roundabouts in Morocco

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Abstract. Roundabouts have increased in a significant way in recent years in Moroccan cities as they have been seen as a solution to congestion problems and traffic safety issues. However, roundabouts are relatively new to Moroccan drivers and the rules of priority to which the users are accustomed are reversed in roundabouts. This can lead to confusion and misleading. The overall objective of this study is to identify roundabout features that appear to play a role in the difficulties that drivers encounter when crossing roundabouts. This paper will present a comprehensive understanding of what is required of drivers when crossing roundabouts. We then predict failures that can occur at roundabout using our driver error taxonomy. A case study of two roundabouts in Morocco is analyzed as illustration. The paper concludes with implications of the findings to future design.

1 Introduction

Today, Moroccan cities are experiencing, as elsewhere in the world, congestion problems characterized by increased travel time, and even bottlenecks. This congestion is therefore a result of high volume of traffic, and little available space.

In the field of urban planning, the concept of "roundabout" thus appears as a solution to these problems and is now gaining wide use across Morocco.

Indeed numerous studies [1-4] have found that roundabouts are quite advantageous regarding traffic safety compared to conventional intersections. In addition extensive studies have been carried out on benefits of roundabouts in the following areas: traffic calming effects due to the creation of a low speed environment and the elimination of conflict points, reduced delay and concomitant emissions [5-7], capacity and quality of traffic flow [8].

Although roundabouts provide many benefits, there are some disadvantages as well. The primary drawback is that the rules of priority to which the users are accustomed are reversed in roundabouts. The priority is giving to circulating traffic rather than entering traffic. This means that the driver entering the roundabout must give priority to driver that comes on his left.

However, the term "roundabout" should not be confused with other traffic circles such as rotaries and circular roadways. Roundabouts are circular intersections with specific design and traffic control features. These features include yield control of all entering traffic, channelized approaches utilizing splitter island to divide entering and exiting traffic on each leg, and appropriate curvature to ensure that travel speeds on the circulatory roadway are low [9].

In Morocco, the Highway Code defines the roundabout as "an intersection where all traffic merges into and emerges from a one way road around a central island of circular shape, the circulation on this roadway is in a counterclockwise direction". However, it should be mentioned that the Moroccan Highway Code does not explicitly states who has priority between users in roundabouts but stipulates that roads signs must be used to inform road users of obligations, restrictions or prohibitions with which they must comply.

It is therefore, through signage that roundabouts are regulated in Morocco. Since drivers are used to traffic lights telling them what to do, roundabout as a new concept, can be confusing and understanding of its operating rules can take time.

Drawing on this, the aim of our study is to gain a better understanding of drivers' behaviours at roundabouts. In order to properly address this question, we analyze circumstances leading to failures during roundabout negotiation and the cognitive processes that underlie them.

In this article, we first present a detailed analysis of tasks performed by drivers when crossing a roundabout. We also approach the human errors in driving context. Then, we propose our driver error taxonomy while crossing roundabouts. In situ observations are used to collect data relating to the roundabout crossing task. To conclude, we use our driver error taxonomy to analyze and interpret the drivers' errors and to propose measures that can help drivers and therefore enhance road safety.

2 Prescribed task of crossing roundabouts

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. From a cognitive analysis perspective 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. [10]

This can be called situation awareness, formally defined by Endsley [11] as the "perception of the elements within a volume of time and space (Level 1), the comprehension of their meaning (Level 2), and the projection of their status in the near future (Level 3)".

Roundabout can be visually complex requiring that drivers scan several different areas and keep track of several different elements to get the information need to safely pass [12]. So, while crossing roundabouts, drivers have to perform many subtasks in an environment with many rules and complex interactions. Indeed, beyond the formal rules of using the road as defined by the highway codes, the crossing task mobilizes cognitive skills.

In this sense, the approach of our study is descriptive and our analysis underlies the assumption that to properly negotiate a roundabout, drivers need competences more diversified than only the respect of the Highway Code rules.

To determine a formal framework for modeling the roundabout crossing task, the focus is placed on cognitive analysis of the crossing task from Endsley's work [11] combined with the rules of the road at roundabouts.

first as "component", who is sometimes subject to functional failures due to his own adaptations limits, second, as "regulator" who regulates his activity and adjusts it to overcome the problems arising from the different components of the system including him.

We relied also on the work of Nachtergaele and Fleury[13] to define the prescribed tasks in crossing roundabouts (For more details see our previous paper) [14].

Our approach aims at analyzing the prescribed task (what a driver is expected to do to negotiate roundabouts safely) and the effective task (What a driver effectively does) [15], to explore the possible discrepancies between these tasks and their origins.

The technique of Hierarchical Task Analysis (HTA) (See [16]) is carried out to collect information on the tasks and to determine key functions performed by drivers as they approach and navigate through roundabout.

The first step was to divide the roundabout crossing task into subtasks. Within each segment (approach, entry, within the roundabout, exit), we have identified subtasks that drivers must consider to safely cross the roundabout. Each task accomplished by the driver involves information that needed to be obtained , clues that needed to be understood, decisions that needed to be made, and actions that needed to be taken.

The Figure1 below, shows the subtasks that divers must perform when negotiating roundabouts.

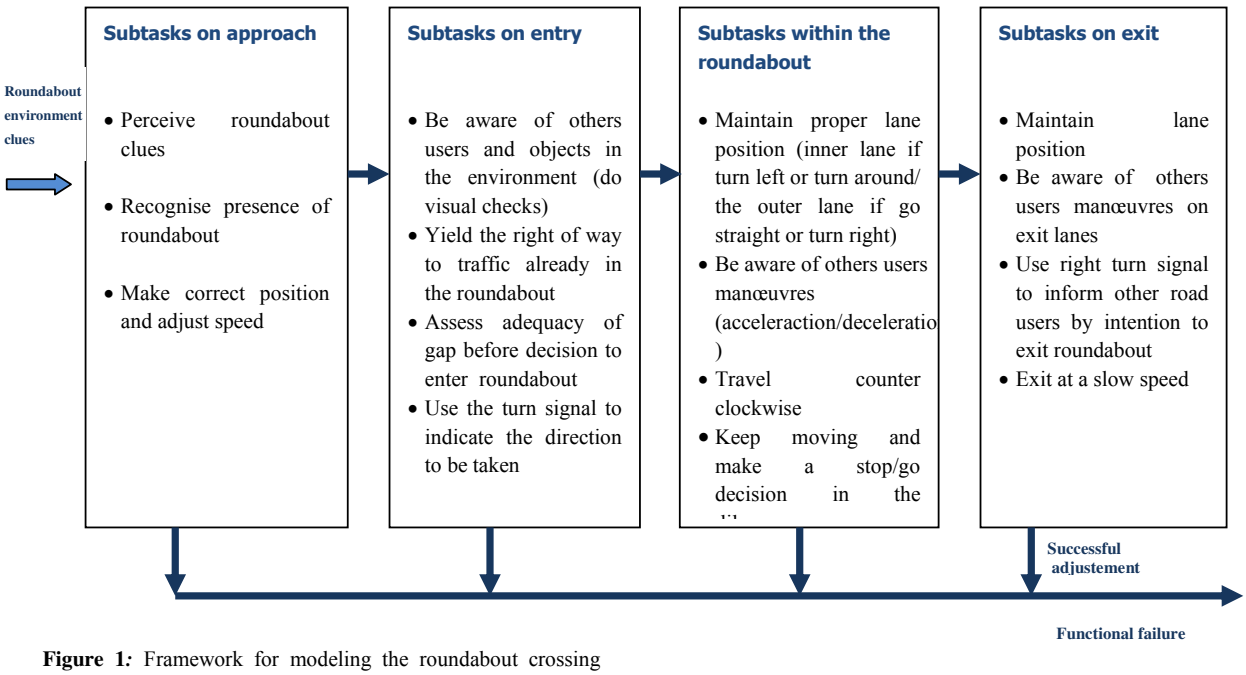

Figure 1*:* Framework for modeling the roundabout crossing task

3 Human functional failures in driving context

In driving context, as stated by numerous authors [17-19] it is important to consider the driver in a double status:

Indeed, the road environment and temporary factors such as the presence of others road users and weather conditions can affect driver behaviour, also factors involving the driver's state (fatigue, stress, illness...) will affect driver's perception of the road and the behaviour

that he thinks is appropriate for the road. In order to avoid any ambiguity, some consensus about terminology seems to be useful.

For the purposes of this paper, "human error" refers to "human dysfunctions" and will be reported with the label of "human functional failures" described by Van Eslande and al [17] such as following: "the impairment of one (at least) of the functions that usually allows the operator to adapt to the difficulties he meets when fulfilling his task".

According to Leplat and Hoc [15], "error" reveals the discrepancies between the prescribed task and the real task, it must be considered as the symptom of the difficulties encountered by the operator in carrying out its activities within a given context.

The explanatory factors of errors correspond to the factors coming from the context, the person, and so on that have favored the emergence of a functional failure.

In the scientific literature, different taxonomies of human errors have been proposed in several areas to serve as descriptive or theoretical tools.

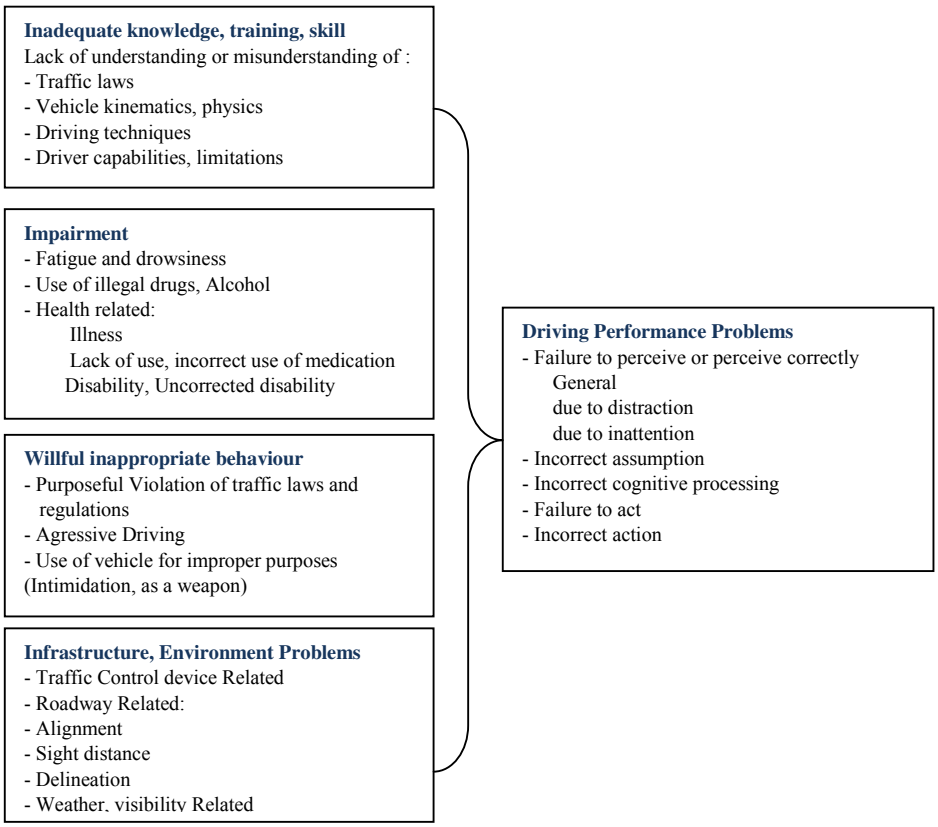

Figure 2: Contributing factors taxonomy (source [20])

4 Proposal of driver error taxonomy when crossing roundabouts

The taxonomy of errors can be useful to deeper understanding of situations that are prone to errors and to find corrections to these situations. In our driver error taxonomy, emphasis has been placed on the multiplicity of contributing factors. The subtasks chain presented in "Figure. 1" was used in our taxonomy in order to identify a comprehensive set of errors that may lead to an incident (such as a near miss) or accident (crash) at roundabouts.

Our study was based on the taxonomy of contributing factors of errors developed by Wierwille and al [20]. One of the innovative features of this taxonomy is that it focuses on the causes of driver errors. It provides an explanation of not only *what* happened, but also *why* it happened. The fundamental concept underlying the taxonomy is that failures in driver performance are a result of a combination of contributing factors. Four major categories of contributing factors have been identified: 1-Inadequate knowledge, training, and skill, 2-Impairment, 3-Willful inappropriate behavior, and 4-Infrastructure and environment. This taxonomy is presented in figure 2 below:

The errors analysis was carried out using a standard human HAZOP (Hazard and Operability) technique to provide a description of potential errors that can arise at each subtasks.

To each of these subtasks we have associated the cognitive functions necessary to achieve it, and which are more or less preponderant in the subtask concerned. Once the failure has been identified, the sources and types of

errors have been described based on the literature review of research that focused on sources of errors [13, 20, 21].

The table 1 below presents our driver error taxonomy when crossing roundabout and their explanatory elements.

Table 1. Our driver error taxonomy at roundabouts

N	task	Domain	Internal error mode	Deviation	Errors Type	Endogenous Factors	Exogenous Factors
1	**Subtasks on approach**						
1.1	Perceive roundabout clues	Perception	Miss see No detection (visual) See too late	Failing to perceive roundabout	Perception errors	Inattention Lack of Vigilance Distraction Overload Impairment due to dysfunctions	Roundabout signs missing, obscured or not clearly visible, Poor weather conditions Poor Visibility of roundabout
1.2	Recognise presence of roundabout	Memory	Forget information Miss recall information Wrong information obtained	Failing to recognise roundabout	Recognition errors	Memory confusion Overload Misinterpretation Knowledge problem (user is unfamiliar with roundabout	Poor weather conditions Inconsistency of signage location and size between roundabouts Poor legibility of roundabout
1.3	Make correct position Adjust speed	Decision Action	Decision omitted Action too late Action too early	Failing to formulate safe stopping strategy Failing to control speed on approach	Decision errors Performance errors	Distraction Time pressure Inadequate model mental Knowledge problem (user is unfamiliar with roundabout) Impairment due to dysfunctions	Angle of approach affects the user's judgements Long sighting distance available Poor weather conditions Crowded and complex traffic flow
2	**Subtasks on entry**						
2.1	Be aware of users and objects in the environment (visual checks)	perception	Miss see No detection (visual)	Failing to stop behind queued vehicle	Perception errors	Expectation Lack of Vigilance Distraction Time pressure Impairment due to dysfunctions	Crowded and complex traffic flow Road layout inciting drivers to travel at an inappropriate high speed
2.2	Yield the right of way to traffic already in the roundabout	Decision Action	Decision omitted Action too late Deliberate violation	Failing to yield the right of way to vehicles in the roundabout	Decision errors Recognition errors	Inadequate model mental Knowledge problem (user is unfamiliar with roundabout) Confusion Distraction Impairment due to dysfunctions	Poor Visibility of roundabout Poor weather conditions No appropriate roundabout signs Crowded traffic which may lead to unsafe crossing
2.3	Assess adequacy of gaps for entering	Decision	Lack of strategy poor strategy late strategy	Accepting an unsafe gap distance Conflict in roundabout	Decision errors	Low perception of risk Misinterpretation Knowledge problem Decision overload	High traffic flow Insufficient capacity of roundabout leading to the formation of queue and increasing risk taking behaviours Poor visibility Poor weather conditions
2.4	Use the turn signal to indicate the direction to be taken	Decision Action	Decision omitted Action too late Wrong action	Signal driving direction omitted Failing to use the turn signal to indicate the direction	Decision errors Performance errors	Distraction Time pressure Knowledge problem overload	Poor legibility of roundabout
3	**Subtasks within the roundabout**						
3.1	Maintain proper lane position	Decision Action	Decision omitted Action too late Wrong action	Failing to detect proper lane when entering	Decisions errors Performance errors	Inadequate model mental Knowledge problem (user is unfamiliar with roundabout) Impairment due to dysfunctions	Insufficient capacity of roundabout High Traffic flow
3.2	Be aware of other users acceleration/ deceleration	perception	Miss see No detection (visual)	Failing to avoid conflicts with others users	Perception errors Recognition errors	Inattention Lack of Vigilance Distraction Time pressure Impairment due to dysfunctions	Insufficient capacity of roundabout High Traffic flow Poor Visibility Poor weather conditions
3.3	Travel counter-clockwise	Action	No performed action Deliberate violation	travelling clockwise	Performance errors	Confusion Time pressure Knowledge problem	Insufficient capacity of roundabout leading to the formation of queue Poor legibility of roundabouts
3.4	Keep moving make a stop/go decision in the dilemma zone	Action Decision	Action too late Wrong action decision omitted decision too late	Stop at roundabout and refusal of priority	Performance errors Decision errors	Confusion Distraction Inadequate model mental Knowledge problem (user is unfamiliar with rules of priority) Impairment due to dysfunctions	Poor visibility Poor legibility of roundabouts High speed of non priority users
4	**Subtasks on exit**						
4.1	Maintain lane position	Decision Action	Decision omitted Action too late Deliberate violation	Changing lanes incorrectly when exiting	Decision errors Performance errors	Confusion Time pressure Knowledge problem Decision overload	High traffic flow Insufficient capacity of roundabout
4.2	Use right turn signal to signal intent to exit	Decision Action	Decision omitted Action too late Wrong action	Signal driving direction omitted Failing to use right turn signal to signal intent to exit	Decision errors Performance errors	Distraction Time pressure Knowledge problem (user is unfamiliar with roundabout)	Poor legibility of roundabouts
4.3	Be aware of others users on exit lanes	Perception	Miss see No detection	Failing to avoid conflict with others users	Perception errors Recognition errors	Inattention Lack of Vigilance Distraction Time pressure Impairment due to dysfunctions	Insufficient capacity of roundabout High Traffic flow Poor Visibility Poor weather conditions
4.4	Exit at a slow speed	Action	Action omitted Action too late Wrong action	Failing to control speed on exit	Performance errors	Confusion Time pressure Knowledge problem	Poor legibility of the exit Exit radius too tight

The proposed taxonomy table aims to gain an in-depth understanding of deviations that are likely to occur when crossing roundabout and their nature (errors type). Emphasis is placed on endogenous factors (driver state) and exogenous factors (environmental and contextual conditions) that can contribute to these errors.

One of the most important roles of this taxonomy is to provide a framework that can be used in retrospective analysis (accident or incident) to determine human causes and weakness in design, or in prospective analysis to predict possible errors. It constitutes a starting point for a more accurate and consistent classification of human functional failures at roundabouts.

To validate this taxonomy practically, we have applied it to the assessment of drivers' behaviours at roundabouts in Rabat, Morocco. A further goal was to make recommendations to attenuate drivers' errors, and thus to improve traffic safety.

5 Study Methodology and main findings

5.1 Research methodology

The research reported in this article was undertaken at two different roundabouts in Rabat, Morocco. In term of research methodology, our study was based on in situ observations. The roundabouts studied were observed for different random periods of time (30 minutes to 1 hour). The observations were based on an observation sheet developed to carry out the assessment, and to examine whether it would be possible to identify characteristics of roundabout that coincide with a higher likelihood of unwanted events. For each subtasks involved in crossing roundabout, the observer had to check if all subtasks required were accomplished by the driver and to mark missing, incorrectly, or unrequired one. The observer also counted the frequency of different driving manoeuvres, (e.g. lane-changing, overtaking). These measures served to calculate error rates for different driving tasks when negotiating roundabouts.

The sample established was composed by 184 vehicles observed (21 of taxi drivers and 163 drivers of other vehicles). Two-wheeled vehicles and pedestrians were excluded from our study.

5.2 Main findings

5.2.1 Overall numbers of deviations observed

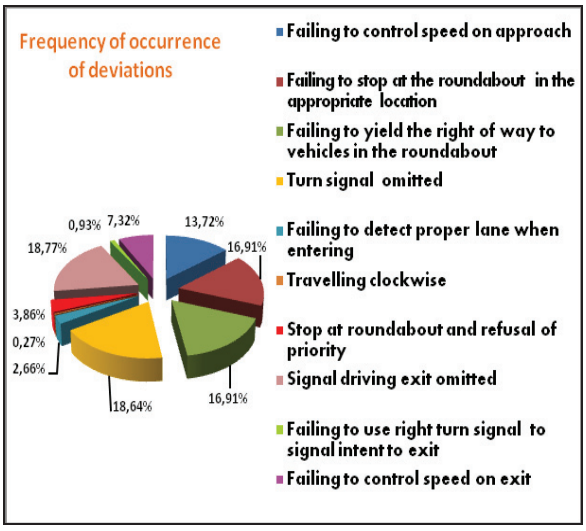

Figure 3: Frequency of occurrence of deviations

The results show that the most observed deviations, concern the omission of the turn signal either at the exit or to indicate the direction with a percentage of occurrence of more than 18.5% each, followed by the non-respect of the priority rule and failure to stop at the roundabout in the appropriate location, with a percentage of almost 17% for each failure. The percentage of vehicles that did not slow down when approaching the roundabout is also important with 13.7%.

These findings make it possible to state that the majority of failures are located in the approach and entry of the roundabout, and account for more than 66% of the observed deviations. These deviations are related primarily to perception and recognition errors, and can be explained using our driver errors taxonomy by endogenous and exogenous factors.

Concerning endogenous factors, these failures can be induced by the lack of knowledge about priority rules, problems of distraction and inattention, lack of knowledge of roundabout features for unfamiliar users, the use of mental model inappropriate, or even the time pressure inducing a bad assessment of gap for entering.

For exogenous factors, they are mainly related to the poor readability and visibility of the roundabouts studied (signs damaged and poorly maintained, appropriate markings were absent), the excessive generosity of their dimensioning and the disturbances related to the density of traffic in the transit roads in which these roundabouts are arranged.

5.2.2 Deviations by types of users

The following graph outlines the distribution of deviations by types of users.

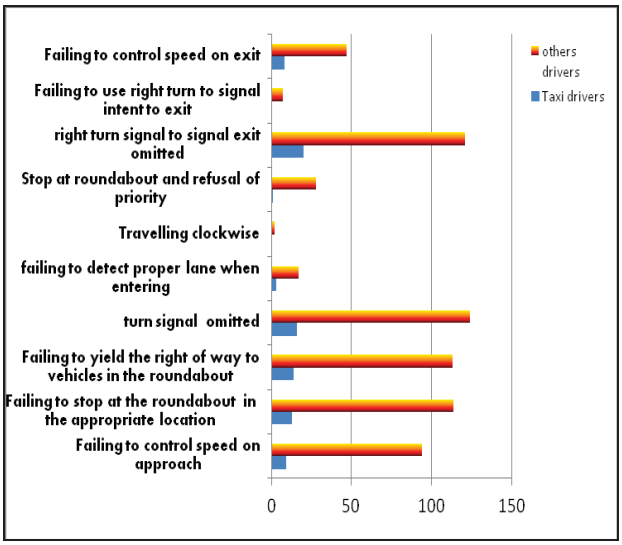

Figure 4: Deviations by types of users

Our analysis of problems encountered by drivers when crossing roundabouts reveals a difference between the two samples (taxi driver and other drivers). This indicates a particularity of errors that concern the two driver types.

It was observed that taxi drivers were more involved in the failures to detect proper lane (38% against 28% for the other vehicles) and the omission of the turn signal at the exit of the roundabout (95% against 74% for other users). The excessive self-confidence that may exist among Taxi drivers could be advanced here as an explanation.

The percentage of errors related to the failure to stop at the roundabout in the appropriate location, to yield the right of way to vehicles in the roundabout, and to indicate to other vehicles the direction to be taken were almost the same for both types of users. Overall, more than 76% of the drivers (cars and taxis) observed did not signal the

direction they were going to drive, and more than 66% failed to give way to priority vehicles.

5.2.3 Signage at roundabouts

Signalling is the most problematic aspect of the roundabouts in Moroccan cities. Indeed, the Economic Commission for Africa highlighted in its report 'Road Safety in Morocco [22] that 'the urban environment suffers from multiple dysfunctions. Roundabouts having the same technical characteristics with similar traffic conditions have different signage from one city to another or even within the same city". This statement is consistent with our findings. Indeed some aspects of the current signage at roundabouts visited are not optimal, it was observed that:

- Roads signs are not always conspicuous due to their size, colour, and position;
- Warning sign which indicates the presence of a roundabout ahead wasn't always used at roundabouts visited;
- At some locations a mixture of road signs and other signs for the public could be seen as confusing or conflicting. An example is "advertising sign" posted with a "yield sign" at one of the roundabouts visited;
- It was noted that "yield signs" were worded differently at roundabouts visited. The sign at one roundabout reads "give way", whereas the sign at another roundabout reads "you don't have priority". This discrepancy increases the ambiguity of the instruction.

5.2.4 Suggestions to improve safety

Recommendations can be made to improve traffic safety at roundabouts in Moroccan cities. It should first be pointed out that addressing the urban planning problem in Morocco with regard to road safety requires a comprehensive and holistic approach at several distinct levels:

DRIVERS:

The ignorance of priority rules at roundabouts can affect the performance and traffic safety. Efforts must be done on educating drivers and introducing safety campaigns to raise awareness among road users in and around roundabouts. Also inclusion of more training and assessment on roundabouts in the driving test, both in the practical and theory tests would help to reduce the number of incidents involving new drivers at roundabouts.

- URBAN PLANNING

The safety of roundabouts can be improved through better analysis of users' needs at the design phase of the project.

- ROUNDABOUTS FEATURES

In order to design well functioning roundabouts, we need to take into account drivers' limitations, thus actions may notably consist in:

- Promoting visibility to meet the driver expectations, ensuring that the driver will not be surprised by the roundabout or the reactions of other drivers. It is suggested to increase visibility of warning signs, with reflectors or luminance to alert drivers and provide them with additional time to take the appropriate decision.
- Roundabouts with sufficient capacity to avoid queuing too long or too frequent. This question raises the need to situate any action in the implementation of new roundabouts on the basis of a good knowledge of the evolution of urban mobility.
- Improving readability of roundabouts through clear, uniform, and visible signs.

6 Conclusion

The taxonomy of driver error developed, aims to provide an operational framework to enhance understanding of human functional failures, consistent with cognitive concepts and specifically adapted to the driving task of crossing roundabouts. It could serve as a good basis for analysis of deviant behaviours that are likely to occur at roundabouts not only in Morocco but in other countries worldwide.

The results of our study address that there is a general lack of awareness and understanding on the part of most drivers regarding roundabouts. This is enhanced by inconsistencies in the road signs at roundabouts, which can be confusing and misleading.

More generally it can be emphasized that road scene elements and traffic condition play a role in the difficulties that drivers encounter when crossing these intersections.

The analysis leads to the general conclusion that roundabouts, with all kinds of traffic users, are too complex and extremely difficult to negotiate, hence the need to set up roundabouts which facilitate visibility and predictability for all users. This means that roundabouts must be designed in a consistent and standardised manner.

The research outcomes suggest that road authorities have to consider the roundabout safety impacts when planning and evaluating new roundabouts.

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