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IN-DEPTH INVESTIGATION OF CONTRIBUTING FACTORS TO CAR-MOTORCYCLE ACCIDENTS IN BUDAPEST CITY

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Abstract

Car-motorcycle accidents have been reported higher in recent years in Hungary due to increasing number of motorbikes on road. Car-motorcycle collisions mostly lead to fatal and seriously injured accidents mainly due to the vulnerability of motorcyclists and other related factors. The crash investigation studies aim to analyze the main contributing factors that cause fatal road accidents and injury outcomes. The main goal of this study is to evaluate and compare the contributing factors to car-motorcycle accidents in Budapest city by using a microsimulation tool. The procedure utilized the statistical analysis and data sampling to categorize car-motorcycle accidents by dominant accident types based on collision configurations. The police report is used as a data source for designated accidents and simulation models are plotted according to scale (M 1:200). The simulation crash study results observed the main contributing factors to car-motorcycle accidents such as driver behavior, rider behavior and view obstruction. The comprehensive in-depth investigation also found that most of the car drivers and riders could not perform collision avoidance manoeuvres before the collision. This study can help the traffic safety authorities to solve road safety issues by considering the main contributing factors to car-motorcycle collisions. The study also proposes safety measures to avoid car-motorcycle accidents in future.

Keywords: Car-motorcycle accidents, accident types, contributing factors, in-depth investigation, accident reconstruction

1. INTRODUCTION

The Global status report on road safety stated that the number of annual road traffic deaths has reached 1.35 million. More than half of global traffic deaths are among motorcyclists, pedestrian and cyclist who are still very often neglected in road traffic system design in many countries [1]. In 2017, motorcyclists accounted for 15% of road accident fatalities on EU roads, which is the second highest rate after pedestrians (21%) among vulnerable road users. In addition, Hungary's road safety performance is below the EU average. In

2018, 64 people per million inhabitants died on Hungarian roads, representing a 1% increase compared to the previous year [2]. The long-term trend shows that traffic in Hungary has become safer for all road user groups but to a lesser extent for motorcyclists [3]. According to the Hungarian Central Statistical Office (KSH) data, there were 668 road accidents causing personal injury by motorcycles in 2018, a 4% rise as compared to 2017 [4].

The situation analysis of the Road Safety Action Program observes that most of the accidents are caused by human-related factors, thus handling them develops the most dynamic target of road safety actions [5]. The National Highway Traffic Safety Administration’s (2008) report [6] specified that human error is the serious reason for 93% of crashes.

Motorcycle riders are one of the vulnerable users among the other road users. The number of motorcycles on the road is increasing with time, thus it can be expected that motorcycle accidents fatalities will remain a significant issue for road safety [7]. Some differences in powered two-wheelers characteristics such as size, speed and specific behavior contribute to their vulnerability on the road. Due to this vulnerability, the riders require to apply a maximum amount of attention in driving conditions to ensure their safety. This is important mainly since car drivers may perform behaviors that place them in danger [8].

Elliott et al. (2007) [9] examined that the car driver’s behavior was the main contributing factor in traffic accidents involving motorcyclists. Different types of accidents should be considered when analyzing motorcyclists’ behavior and consequences.

Accidents also involved specific situations such as "looked-but-failed-to-see" where the visual perception of related information is interrupted. Despite conspicuity and environmental display of objects, the combination of some driver/road specificities leads to behaviors, which do not regard specific hazards as critical. Some physical and psychophysical constraints on vision could describe perception failure [10]. A review study assessed this problem comprehensively and concluded that only two categories of error are seen to meet the criteria for genuine “looked-but-failed-to-see" errors: one results when individuals search the traffic environment over-selectively, the other results when individuals search for features which distinguish hazardous from non-hazardous items, but fail to integrate those features into a coherent image representing danger [11].

An in-depth study was carried in the UK which observed that the most common motorcycle accident occurs when a vehicle fails to give way to an oncoming motorcycle while coming out from a side road onto the main carriageway [12]. A right-of-way violation was found to be the key factor in most motorcycle accident studies. A typical case would involve a car moving out from a junction into the path of an approaching motorcycle. The effects of right-of-way violation causing rider injury severity were primarily studied for motorcycle–car angle crashes [13, 14]. These could be further described as; the road user did not identify the danger of driving fast in an area with poor visibility and did not decrease their speed according to the right of way [15].

The previous study observed that the driver's attitudes about the social acceptability of speeding or risky driving may be the strongest influence on the likelihood of insecure driving behaviors [16]. Also, the risk of injury increases with impact speed. However, exact impact speeds are not mostly available in most of the crash reports [17].

Pre-crash events were mostly observed as the main factors in the classification of accident configurations [18]. The reconstruction of a road vehicle accident is a multidimensional engineering task intended to reconstruct the cause of accident occurrence and its course [19]. Police-reported accident data could be useful for in-depth analysis of crashes with a good deal of valuable information such as vehicle types, road types, and locations involved [20]. Moreover, the comprehensive in-depth motorcycle crash study is a useful method to adopt safe systems in road safety using real-world crashes data [14, 21].

This paper mainly analyzed the various contributing factors to car-motorcycle accidents by accident types in Budapest city. In-depth investigation is performed for frequent car-motorcycle accidents categorized by collision configurations. The study also observed the collision avoidance manoeuvres performed by both partners such as car and motorcycle for each accident. Countermeasures are also discussed from car driver and motorcyclist perspectives to avoid car-motorcycle accidents in future.

2. METHODOLOGY

A flowchart detailing the scope and research methodology is shown in Figure 1. Firstly, from the statistical data analysis, the car-motorcycle accidents are identified and categorized by accident types. Secondly, from stratified data sampling, fifty car-motorcycle accidents are selected by dominant accident types for in-depth analysis. Subsequently, the in-depth analysis is performed to develop the simulation models and utilize these for accidents reconstruction. After that, Virtual Crash software is used to simulate the specified accidents for

5 seconds during the collision. Finally, the simulated data is used to measure the contributing factors to car-motorcycle accidents. From the analysis of results, the possible safety measures are proposed for avoidance of car-motorcycle collisions in future.

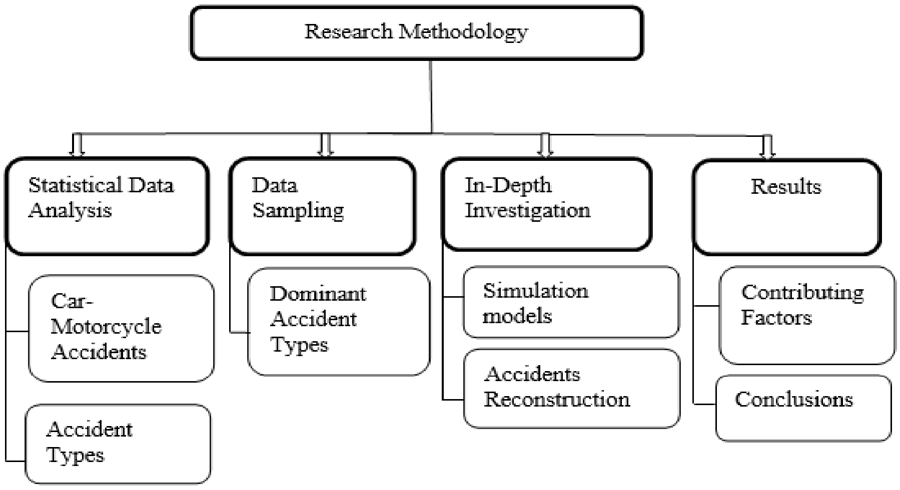


Figure 1. Scope and research methodology

2.1. Statistical data analysis

Road accident data for the 2011-2014 period was collected from the Hungarian Central Statistical Office (KSH). The accident data analysis disclosed that there were about 2,673 car-motorcycle accidents during the specified period. The study considered the accidents which happened in the built-up area in Budapest, the capital city of Hungary. Furthermore, from the collected accident data, those accidents are selected which involve only one car and one motorcycle. Furthermore, the accident data analysis observed total nine accident types. However, six dominant accident types are categorized based on the frequency occurrence of accidents. These accident types are listed here: (a) car and motorcycle both travelling straight and the same direction; (b) car and motorcycle both travelling straight and opposite direction; (c) car and motorcycle both travelling the same direction and one turning; (d) car and motorcycle both travelling the opposite direction and one turning; (e) car and motorcycle coming from adjacent directions and without turning; (f) car and motorcycle coming from adjacent directions and turning. Based on percentage occurrence (rate) of accidents under specified accident types, fifty accidents are selected by data sampling for in-depth analysis. The police report is used as a data source for selected accidents and simulation models plotted according to scale (M 1:200). The previous study also collected statistical data from the police for measurement of the scale of traffic risks and identification of major road safety problems. Unfortunately, police on the scene of an accident have no chances or time to identify the actual cause of the collision [22]. The important parameters considered in observed simulation models are the participant's position, direction, view obstructions, speed, braking and swerving. Figure 2 presents the recent car motorcycle accident data which shows a higher number of motorcyclist's fatalities as compared to car drivers.

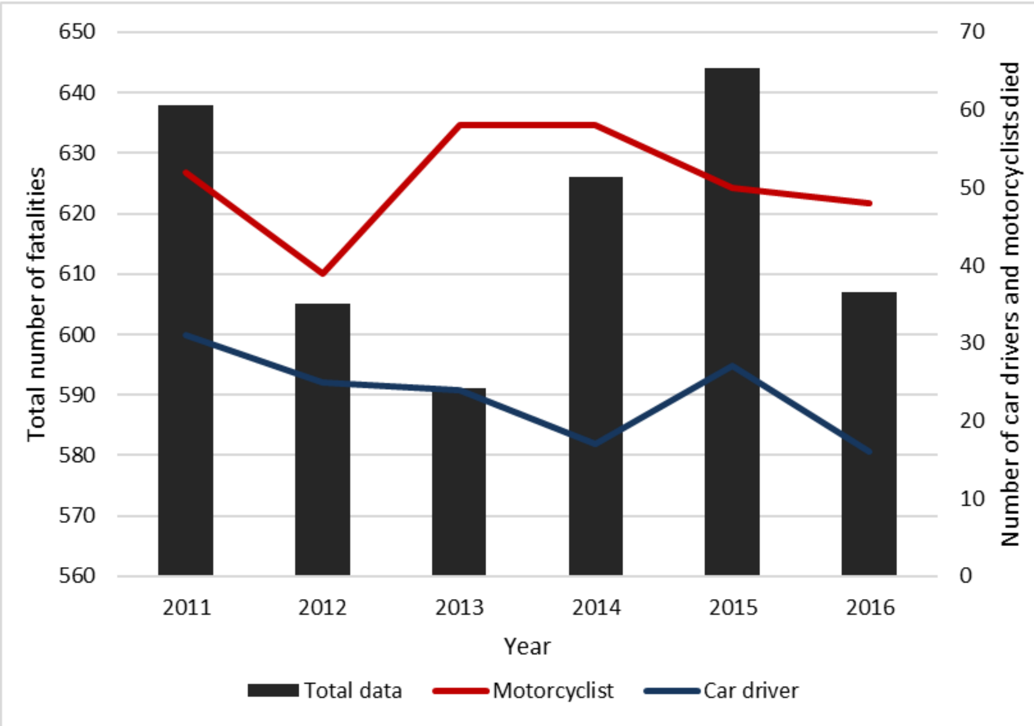


Figure 2. Number of fatalities in car-motorcycle accidents

The demographic characteristics of involved car drivers and motorcycle riders are tabulated in Table I. The mean and standard deviation values are measured for some characteristics such as age and duration of license possession. The results showed that most of the motorcyclists involved in car-motorcycle accidents were young and have less driving experience as compared to car drivers. Also, most of the car drivers and motorcycle riders were male.

Table 1. Demographic characteristics of car drivers and motorcyclists

Variables	Car drivers	Motorcyclists
N	50	50
Age Mean SD	32.65 5.25	24.98 3.54
Gender (n) Male drivers Female drivers	 43 7	 48 02
Duration of license possession Mean SD	 15.16 6.17	 6.41 3.02

2.2. Virtual crash simulation

To measure the contributing factors to car-motorcycle accidents, the investigation included the full reconstruction of the accidents in Virtual Crash software 2.2. The car-motorcycle accidents are simulated for 5 seconds during the collision by using police reported simulation models. This simulated time period is considered important because drivers and riders have to perceive and react according to aware/unexpected situations. The reaction time of car drivers was observed around 0.70–0.75 s when fully aware and 1.25–1.5 s for unexpected situations [23]. The reaction time of motorcyclists under fully aware or unexpected conditions was measured about 0.7–0.9 s [24]. The important parameters considered for simulation analysis are driver behavior, rider behavior, view obstructions (stationary and mobile), relative angles, impact speed and collision avoidance manoeuvres (braking, swerving). To observe view obstruction from the driver point of view, the camera emulator tool is used on the left, right and top mirror positions. The relative angles between car and motorcycle are also measured within specific time intervals based on the simulation data. All this information increases the accuracy and reliability for in-depth investigation of accidents. Figure 3 presents a simulation image of car-motorcycle accident as an example.

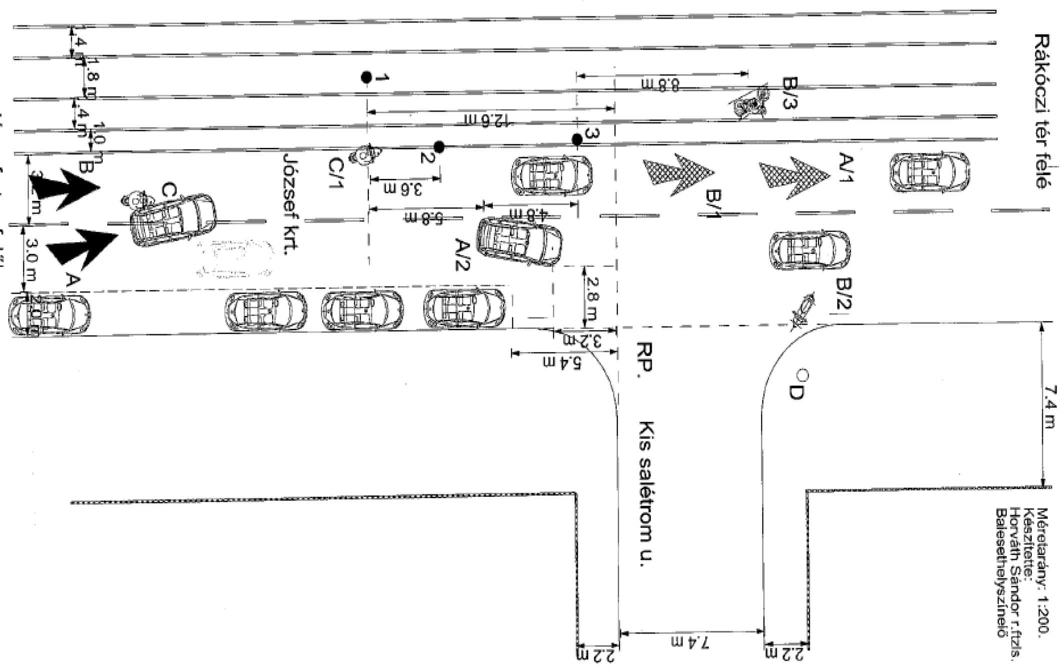


Figure 3. Simulation image example

3. RESULTS AND DISCUSSION

In-depth crash investigation methods have commonly been utilized to investigate the most probable involved factors to the fatal crash and injury outcomes, using data collected from the vehicles, road users, crash site and police or traffic incident reports where available [25, 26, 27].

In-depth analysis identified the six main accident types based on frequency occurrence and car-motorcycle alignment images are shown for each accident type. Virtual Crash software has been utilized as a tool to reconstruct the car-motorcycle accidents and the results are tabulated in Table 2. The simulation results showed that accidents occur in different configurations. The purpose of grouping the accident configurations is to investigate the participant's behavior and related parameters at the precipitating event. The most frequent accident type observed is the one that includes vehicles coming from the same direction and other vehicle turning, which was about 24%. The least frequent accident type is the following: vehicles coming from the opposite direction and straight ahead, which is about 4%. It is also noticed that most of the collisions (80%) took place at an intersection by considering the location of accidents in the simulation models. A previous study observed that the situation where vehicle "A" crosses the road and the path of the opponent vehicle "B", which is going straight or turning, is more common and more severe than any other. This situation was observed for about 70% of all intersection accidents [28].

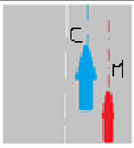
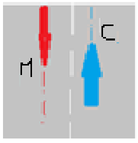
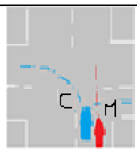
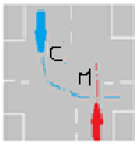
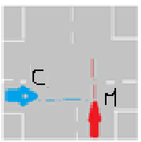
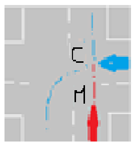
Relative angles are measured between car and motorcycle towards the line of sight at 5 seconds before the collision. The relative heading angle represents the angle between the car and the motorcycle at the time of contact, expressed as a positive angle, clockwise from the vertical where zero degrees corresponds to both vehicles being pointed in the same direction [25]. It is observed that the most frequent (60%) observed relative angles are between 0° to 90°. Furthermore, the impact angles are measured between car and motorcycle at the moment of collision. Results showed that the most frequent (64%) observed impact angles are between 0° to 90°, almost like the relative angles results.

View obstructions can be defined as the sight of view not visible due to stationary or mobile view obstructions. Results showed that there is contribution of stationary view obstructions (buildings, vegetation, and parked vehicles) for 20% car-motorcycle accidents. Also, there is observed contribution of mobile view obstructions (cars and large buses) for 16% car-motorcycle accidents. The option ‘none’ evaluated that there is no type of view obstructions observed in other cases.

Analysis of the results showed that the variety of driver and rider behavior factors is involved in different types of collisions. Human behavior is observed as the most important factor in previous accident studies. Car driver and motorcycle rider behavior led to fatal car-motorcycle accidents [29, 14]. Firstly, the current study analyzed the car driver behavior in the car-motorcycle collision. The most frequent observed driver behavior factors are perception failure, failing to yield, traffic scan error and high speed. Perception failure by car drivers is the main factor observed in 34% of accidents. Previous studies have revealed that human error such as perception failure (both on the part of the rider and other road users) was the most common factor in powered two-wheelers (PTW) crashes [25, 30]. Traffic scan error is also observed higher about 24% in car-motorcycle accidents as compared to other driver behavior involved factors. Secondly, rider behavior is observed in accidents simulation analysis. The most frequent observed rider behavior factors are high speed, critical overtaking, wrong lane and fail to yield. It is observed that high impact speed involved about 28% in car-motorcycle accidents. Impact speed can be described as the observed speed of the motorcycle at the time of the collision. The study found that motorcycles’ poor conspicuity may be intensified with higher speed, which may decrease their detectability from a turning motorist’s perspective [31, 32]. Critical overtaking is also observed higher, about 22% in car-motorcycle accidents as compared to other involved rider behavior factors.

Data analysis results showed that most collision avoidance manoeuvres were not finally attempted by car drivers and motorcycle riders. Collision avoidance manoeuvre is an action performed by the participant to avoid the aware/unexpected collision. Results evaluated that in car-motorcycle collisions, 88% of the car drivers attempted no collision avoidance manoeuvres and 12% of the car drivers attempted some sort of collision avoidance manoeuvres (0% by braking, 12% by swerving). Results also evaluated that 52% of riders attempted no collision avoidance manoeuvres and 48% of the riders attempted some sort of collision avoidance manoeuvres (24% by braking, 24% by swerving).

Table 2. In-depth Investigation results

Summary	Vehicle From	Same Direction	Opposite direction	Same Direction	Opposite Direction	Adjacent Direction	Adjacent Direction
	Another Vehicle	Straight ahead	Straight ahead	Turning	Turning	Without turning	Turning
Parameters	Categories	 Frequency (%)	 Frequency (%)	 Frequency (%)	 Frequency (%)	 Frequency (%)	 Frequency (%)
No. of Accidents (%)	-	8 (16%)	2 (4%)	12 (24%)	10 (20%)	8 (16%)	10 (20%)
Relative angles (Degree)	± (0-90) ± (90-180) ± (180-270)	0 (0.0%) 8 (100%) 0 (0.0%)	2 (100%) 0 (0.0%) 0 (0.0%)	0 (0.0%) 8 (67%) 4 (33%)	10 (100%) 0 (0.0%) 0 (0.0%)	8 (100%) 0 (0.0%) 0 (0.0%)	10 (100%) 0 (0.0%) 0 (0.0%)
Impact angles (Degree)	± (0-90) ± (90-180) ± (180-270)	0 (0.0%) 6 (75%) 2 (25%)	2 (100%) 0 (0.0%) 0 (0.0%)	4 (33%) 8 (67%) 0 (0.0%)	10 (100%) 0 (0.0%) 0 (0.0%)	6 (75%) 2 (25%) 0 (0.0%)	10 (100%) 0 (0.0%) 0 (0.0%)
View Obstructions	Stationary view Mobile view None	0 (0.0%) 0 (0.0%) 8 (100%)	0 (0.0%) 2 (100%) 0 (0.0%)	0 (0.0%) 2 (17%) 10 (83%)	4 (40%) 0 (0.0%) 6 (60%)	4 (50%) 1 (13%) 3 (37%)	2 (20%) 3 (30%) 5 (50%)
Car driver behavior	Perception failure Fail to yield Traffic scan error High Speed Other	4 (50%) 0 (0.0%) 1 (13%) 0 (0.0%) 3 (37%)	0 (0.0%) 0 (0.0%) 1 (50%) 0 (0.0%) 1 (50%)	4 (33%) 2 (17%) 3 (25%) 1 (8%) 2 (17%)	4 (40%) 2 (20%) 2 (20%) 0 (0.0%) 2 (20%)	3 (37%) 2 (25%) 1 (13%) 0 (0.0%) 2 (25%)	2 ((20%) 0 (0.0%) 4 (40%) 0 (0.0%) 4 (40%)
Motorcycle rider behavior	Wrong lane Critical overtake Fail to yield	2 (25%) 1 (13%) 0 (0.0%)	0 (0.0%) 1 (50%) 0 (0.0%)	4 (33%) 3 (25%) 0 (0.0%)	0 (0.0%) 0 (0.0%) 2 (20%)	0 (0.0%) 4 (50%) 0 (0.0%)	0 (0.0%) 2 (20%) 4 (40%)

	High Speed Other	3 (37%) 2 (25%)	1 (50%) 0 (0.0%)	2 (17%) 3 (25%)	6 (60%) 2 (20%)	2 (25%) 2 (25%)	0 (0%) 3 (30%)
Collision avoidance by car driver	Braking Swerving No avoidance	0 (0.0%) 2 (25%) 6 (75%)	0 (0.0%) 0 (0.0%) 2 (100%)	0 (0.0%) 0 (0.0%) 12 (100%)	0 (0.0%) 2 (20%) 8 (80%)	0 (0.0%) 0 (0.0%) 8 (100%)	0 (0.0%) 2 (20%) 8 (80%)
Collision avoidance by rider	Braking Swerving No avoidance	0 (0.0%) 4 (50%) 4 (50%)	2 (100%) 0 (0.0%) 0 (0.0%)	2 (17%) 4 (33%) 6 (50%)	4 (40%) 2 (20%) 4 (40%)	2 (25%) 0 (0.0%) 6 (75%)	2 (20%) 2 (20%) 6 (60%)

A better understanding of the association between motorcyclist injury severity and involved factors such as the human, vehicle, crash characteristics and weather, may enable the identification of appropriate countermeasures [14, 21]. In addition, an understanding of powered two-wheelers (PTW) rider behavior is critical to design appropriate and scientifically based countermeasures [7]. For car-motorcycle accidents in which view obstructions are observed as the main contributing factors, the proposed safety measures are in-vehicle sensors which can warn drivers of a hazardous situation. Also, the active safety devices (e.g. ABS, collision avoidance devices) can provide a warning about an imminent collision or minimize the severity of the collision [33]. For accidents in which contributing factors related to human behavior (car drivers and motorcyclists) are observed, the proposed safety systems are vehicle-to-vehicle communication (V2V) systems, which can share information between vehicles about speed, braking, the direction of travel and location. From a car driver's perspective, timely detection of an approaching motorcycle could signify a way to avoid accidents. Driver training can also help car drivers to make the right decision in a hazardous situation to avoid the collision or minimize the severity of the collision. From a motorcycle rider perspective to improve rider safety, the proposed safety measures are the use of speed warning systems, traffic law enforcement, rider training, high visibility helmets, and road safety campaigns. A study revealed that a 10% speed reduction of a car before a collision can reduce fatal injury by 30% [34]. Previous studies have also indicated that speed warning systems, information flow, preference management and campaigns promoting road safety have resulted in a major reduction in road fatalities [35, 36].

4. CONCLUSIONS

This paper designed to investigate the contributing factors to car-motorcycle accidents in Budapest city with the help of a simulation tool and safety measures are proposed accordingly. The study evaluated and compared the main contributing factors and sub-factors by different accident types. The accident type in which 'vehicle moving in the same direction and another vehicle turning' is observed as the most dominant accident type with the highest number of collisions. The statistical analysis results found that most of the accidents happened in the intersection area with different collision configurations. While, the crash simulation results found the main contributing factors to car-motorcycle accidents such as driver behavior, rider behavior and view obstructions. Subsequently, the most frequent observed driver behavior factors are perception failure and traffic scan error. While the most frequent observed rider behavior factors are high speed and critical overtaking. Furthermore, the study observed that both types of view obstructions such as stationary and mobile view obstructions as contributing factors to car-motorcycle accidents. Moreover, it is noticed that the high speed of rider did increase the possibility of the rider not being seen and of other drivers in the zone to take the wrong decision before the collision. Finally, it is observed that most of the car drivers and motorcycle riders could not perform collision avoidance manoeuvres such as braking and swerving before the collisions.

Safety measures are proposed from both car and motorcycle perspectives to avoid car-motorcycle accidents in future. The study recommends the application of three important road safety rules (3E rules) such as education, engineering and enforcement mainly for motorcycle riders. The 'education' safety rules include the proposition of more training hours and road safety campaigns for motorcycle riders in Budapest city. While the 'engineering' rules include the active-passive safety systems, bright clothes and motorcycles equipped with anti-lock brake systems for collision avoidance and injuries reduction. Also, the infrastructure features including the implementation of appropriate road standards and provision of motorcycle lanes are particularly important to ensure a safe journey. The 'enforcement' safety rules include better compliance with speed limits, seat-belt use and helmet use for safe movements of car drivers and motorcyclists on road.

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