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DOI
10.1016/j.trf.2020.11.008

Publication date
2021

Document Version
Final published version

Published in
Transportation Research Part F: Traffic Psychology and Behaviour

Citation (APA)
Sheykhfard, A., Haghighi, F., Papadimitriou, E., & Van Gelder, P. (2021). Analysis of the occurrence and severity of vehicle-pedestrian conflicts in marked and unmarked crosswalks through naturalistic driving study. *Transportation Research Part F: Traffic Psychology and Behaviour*, *76*, 178-192. https://doi.org/10.1016/j.trf.2020.11.008

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Transportation Research Part F 76 (2021) 178–192

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

Analysis of the occurrence and severity of vehicle-pedestrian conflicts in marked and unmarked crosswalks through naturalistic driving study

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A R T I C L E I N F O

Article history:
Received 29 May 2020
Received in revised form 16 November 2020
Accepted 19 November 2020
Available online 17 December 2020

Keywords:
Driver yielding behavior
Traffic conflict
Pedestrian crossing
Naturalistic driving study

A B S T R A C T

Background: Although many studies have been conducted on the safety of pedestrian crossings, few researches have been focused on drivers' behavior in unmarked crosswalk and marked crosswalk areas. Considering that statistics of pedestrian accidents are not the same in the two types of crossing area, based on the last report of the World Health Organization, it is very critical to evaluate driver yielding behavior to determine the differences in the actions of drivers when encountering pedestrians in the two areas.
Methods: This study was conducted based on surrogate measures of safety (SMoS) collected through a Naturalistic Driving Study on 52 participants in Iran. The study was carried out from April 2017 to April 2018 using the installation of cameras in the private vehicle of the participants. The analysis of the recorded films showed that 956 conflicts have occurred in unmarked crosswalks and 392 conflicts in marked crosswalks, respectively.
Results: A model was developed for driver yielding behavior using binary logistic regression, and showed that yielding rates in unmarked crosswalsk were about fifty percent of the yielding rates in marked crosswalks. Based on the model, it is indicated that the aggressive behavior of pedestrians during the crossing, such as running, zigzag and diagonal crossing, as well as the late detection of pedestrians by drivers resulting from high-speed driving in the unmarked crossing areas, will reduce the yielding behavior rate. Also, using the Swedish traffic conflicts technique, the severity of the conflicts was classified into four general categories: encounter, potential, slight, and serious conflict, through 30 different levels on the basis of conflicting speed and time to the accident. The results showed that pedestrians behavior during conflicts of the group "encounter" and drivers' behavior during conflicts of the groups of "potential", "slight" and "serious", were the principal factors in preventing collision through an evasive maneuver. The results showed that increasing the level of conflict severity, which indicates an increase of the conflicting speed and a decrease of the time remaining to point of a possible collision with pedestrian, causes drivers to yield a harsh-maneuver to prevent collision. Soft-maneuvers such as deceleration and acceleration, as well as harsh-maneuvers such as changing the lane/stop during conflicts were most driver yielding behavior during conflict groups of slight and serious. According to the results of the analysis, the behavior of drivers in marked crossing areas is better than in the unmarked crossing area, leading to safer crossing for pedestrians.

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https://doi.org/10.1016/j.trf.2020.11.008
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Conclusions: This study suggests that the significant differences in driver yielding behavior in the two areas is due to the late detection of pedestrians by drivers and also the less proper action by them in unmarked crosswalk areas. Thus, the probability of accidents in Unmarked Crossing areas is higher than in marked crossing areas. Consequently, the design of improved advanced driver assistance systems to identify the risk of pedestrian accident may improve the driver yielding behavior and thus increase the safety of pedestrians.

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1. Introduction

Unmarked crosswalks (UMCs) are areas with a high risk of accidents for pedestrian crossing. In general, at UMCs, the sudden decision of pedestrians to cross the street leaves little time for the drivers of approaching vehicles. In other words, drivers are often unable to respond immediately to pedestrian behavior because of the lack of prediction about the possibility of the pedestrian crossing in these areas. According to the World Health Organization, 2018), on average, about 23% of the 1.35 million road deaths in the world are pedestrians, mostly at UMCs (World Health Organization, 2018). Iran is a developing country, with pedestrians accounting for about 22% of its annual road deaths (Iran forensic medicine, 2018). Of these statistics, about 75% of pedestrian accidents occur at UMCs (Iran forensic medicine, 2018). Therefore, studying and comparing the behavior of drivers at UMCs and Marked crosswalks (MCs) can lead to a better understanding of the concept of driver yielding behavior (DYB) when facing pedestrians in these areas. An implication of this study is to improve pedestrian safety by implementing appropriate policies on safety crossing at these areas or the development of advanced driver-assistance systems (ADAS) for vehicle–pedestrian conflicts.

So far, many studies have been conducted on accidents and conflicts between vehicles and pedestrians (Chen, Zeng, Yu, & Wang, 2017; Sheykhfard & Haghighi, 2020b; Phillips, Bjørnskau, Hagman, & Sagberg, 2011;Tiwari, Bangdiwala, Saraswat, & Gaurav, 2007; Fontaine & Gourlet, 1997; Layegh, Mirbaha, & Rassafi, 2020), mainly through using accident databases (Mohamed & Bromfield, 2017; Chung & Chang, 2015; Larsen, 2004), questionnaires (Antić, Pešić, Milutinović, & Maslać, 2016; Ram & Chand, 2016; Sucha, 2014), or field studies observers (Gorrini, Crociani, Vizzari, & Bandini, 2018; Wang, Tan, Schwebel, Shi, & Miao, 2018) especially at MCs (Almodfer, Xiong, Fang, Kong, & Zheng, 2016; Sandt et al., 2016). However, in recent years, the use of a fixed camera in MCs near the intersections has become common for pedestrian safety studies as a way to capture more detailed information in comparison with previous methods (Jahandideh, Mirbaha, & Rassafi, 2017; Avinash, Jiten, Shriniwas, Gaurang, & Manoranjan, 2018; Uzondu, Jamson, & Lai, 2018; Zhang, Zhou, Chen, & Chen, 2017). To the best of our knowledge, most of the studies have been conducted at MCs and from the pedestrians' perspective (Jahandideh, Mirbaha, & Rassafi, 2017; Almodfer et al., 2016; Havard & Willis, 2012; Muley, Kharbeche, Alhajyaseen, & Al-Salem, 2017). Therefore, the necessity of a study on pedestrian crossing safety at UMCs and from the drivers' perspective was the main motivation for the present research. Therefore, the purpose of this study was to assess the behavior of drivers facing pedestrians using surrogate measures of safety (SMoS), with a focus on their yielding behavior at different intervals up to the point of possible collision (PPC) with pedestrians in UMCs and MCs areas. The data on the behavior of drivers and pedestrian encounters was explored through a Naturalistic Driving Study (NDS). The outcome of this approach may assist monitoring the behaviors of drivers and pedestrians, which presents the real conditions of road user behavior in the traffic flow (Dingus et al., 2006; Habibovic, Tivesten, Uchida, Bärgman, & Ljung Aust, 2013; Sheykhfard & Haghighi, 2020a). Finally, considering the statistics that pedestrian casualties are not similar in MCs and UMCs area, the research hypothesis is formulated that the possibility of DYB is not similar in different pedestrian approaching times in both areas. Moreover, the research questions of the present study are the following:

- How do the vehicle speed and the time to PPC with pedestrians affect DYB?
- Is the pattern of conflict severity similar between vehicles and pedestrians at MCs and UMCs areas?
- In both areas, what are the models of DYB to avoid collision with pedestrians?

This paper contains 7 sections. The second section elaborates the findings of the past research. The traffic conflicts technique and binary logistic regression are presented as the methods in the third section. In the fourth section, the data collection and case studies are described. The results of DYB model and conflict severity based on Swedish traffic conflict technique will be presented in the fifth section and discussion of the results will be presented in the sixth section. Finally, in the last section, conclusions and future research will be presented.

2. Literature review

As noted in the introduction, pedestrian crossing safety has been evaluated in several studies. Most of the previous studies in pedestrian traffic safety have been devoted to identifying the factors that cause the accidents using accident databases

(Sheykhfard, Haghighi, Nordfjærn, & Soltaninejad, 2020; Mohamed & Bromfield, 2017; Olszewski et al., 2016; Zegeer, Richard Stewart, Huang, & Lagerwey, 2001; Herms, 1972). Later, other methods were adopted by researchers to assess in more detailed the safety of pedestrian crossing with traditional approaches being questionnaires (Sheykhfard, Haghighi, Soltaninejad, & Karji, 2020; McIlroy et al., 2019; (Bellizzi, Eboli, & Forciniti, 2019; Bivina & Parida, 2019; Ram & Chand, 2016; Sisiopiku & Akin, 2003; Taubman - Ben-Ari & Shay, 2012; Zhou & Horrey, 2010), field observations (Brosseau, Zangenehpour, Saunier, & Miranda-Moreno, 2013; Kadali & Vedagiri, 2013; Papadimitriou, Yannis, & Golias, 2009; Papadimitriou, 2012; Said, Abou-Zeid, & Kaysi, 2017; Wang et al., 2018), and driving simulators (Ābele, Haustein, Martinussen, & Møller, 2019; Bella & Nobili, 2020; Charron, Festoc, & Guéguen, 2012; Dommes, Cavallo, & Oxley, 2013; Papadakaki, Tzamalouka, Gnardellis, Lajunen, & Chliaoutakis, 2016). Although these approaches are valuable tools for determining the main causes of accidents through analysing pedestrian behavior, they cannot be used as completely cited approaches to address traffic safety issues for a number of reasons (Alam, 2003; Hoque & Mahmud, 2003; Laureshyn, Svensson, & Hydén, 2010; Organisation for Economic Cooperation and Development (OECD), 1997).

First, accident data are not available in some countries or not all traffic accidents are recorded and reported. Second, complete information about the behavioural features of road users before the accident is rarely available, and accident data mainly describe the conditions in the past. Third, tracking the consequences of a crash report is difficult, which means that, for example, an accident which is recorded as an injury type changes to a fatal type a little later. Fourth, there is lack of accurate information as well as inadequate or limited statistical population in questionnaires. Fifth, using on-site supervisors in observational studies is costly. Sixth, issues of authenticity, validity, initial cost and sickness in driving simulators are not well addressed.

As far as we know, most of the studies using these approaches have been evaluated in the MCs area. Also, in these studies, evaluation of accidents or conflicts of vehicle and pedestrians have been conducted from the pedestrians' side such as videography in intersections using a fixed camera. In other words, few studies have assessed DYB and its corresponding specific crash-avoidance action when facing pedestrians. Although few studies have been carried out at the UMCs areas (Chai & Zhao, 2016; Ekman, 1996; Zhuang & Wu, 2012), the issue of vehicle–pedestrian conflict is still addressed from the pedestrians' side. Researchers have evaluated many studies about the causes of the vehicle–pedestrian conflict in the MCs (Havard & Willis, 2012; Muley et al., 2017; Sheykhfard & Haghighi, 2018), where characteristics and crossing behavior of pedestrians were determined as the main factors affecting traffic safety (Antić et al., 2016; Kadali & Vedagiri, 2013). For example, in some of these studies, the impact of parameters such as pedestrian speed (Brosseau et al., 2013; Zhang et al., 2017), waiting time (Hunter et al., 2015; Salamati, Schroeder, Geruschat, & Rouphail, 2013), crossing without attention to approaching vehicles in the traffic flow (Wu & Xu, 2017), and high-risk crossing style such as running (Habibovic et al., 2013) or zigzag movement (Serag. , 2014) are identified. Also, in some studies, the effects of parameters such as pedestrian gender (Brosseau et al., 2013; Langbroek et al., 2012), age (Olszewski et al., 2016), physical condition (Salamati et al., 2013), the size of the group during passage (Sheykhfard & Haghighi, 2019) have been determined as effective factors on vehicle–pedestrian conflicts. Concerning the studies that have focused on pedestrian behavior, few have been conducted on drivers' behavior and vehicle–pedestrian conflicts. It is important to note that in most of these studies, the main approach of study for collecting pedestrian behavior or vehicle movement is installing a fixed camera at the study site as on top of the tallest building in the area. Based on this, the impact of parameters such as vehicle speed, distance from the vehicle to PPC with the pedestrian, driver gender, driver decision for permission to the pedestrian crossing, and drivers age have been reported as factors affecting the behavior of drivers during vehicle–pedestrian conflicts (Chen et al., 2017; Hunter et al., 2015; Salamati, Schroeder, Geruschat, & Rouphail, 2014; Serag. , 2014).

Therefore, due to some limitations in this type of approach, such as the inability to control car movements at intervals before entering the area covered by the fixed camera, it is impossible to assess the decision of drivers along the roadway. Consequently, studying vehicle–pedestrian conflicts should be carried from the driver side to monitor DYB at various intervals before and at the time of conflicts. Finally, by considering previous studies, it can be concluded that the DYB, as well as the type of driver action during a conflict with pedestrians have not been addressed at the UMCs.

3. Method

3.1. The traffic conflicts technique

SMoS are among the new approaches to road safety analysis. These methods, in addition to being of a preventive-nature procedure, also have not the limitations of the previous approaches, so they are very promising for assessing traffic safety. The Traffic Conflicts Technique is considered the most substantial to collect SMoS for traffic safety studies. The traffic conflict approach is associated with events in traffic, which can cause a collision. A conflict situation is defined as when two or more road users approach each other in time and space to such an extent that a collision is imminent if their movements remain unchanged (Amundson & Hydén, 1977). Fig. 1 shows schematically the conflict area between a vehicle and a pedestrian.

The Swedish Traffic Conflict Technique (STCT) is one of a variety of TCT's that applies time and space situations for estimates of accident risk. This method is one of the oldest, well-tested, and well-validated tool that is still in active use by road safety practitioners. Research on STCT began at the University of Lund in 1970 and was developed by a group led by Hyden in

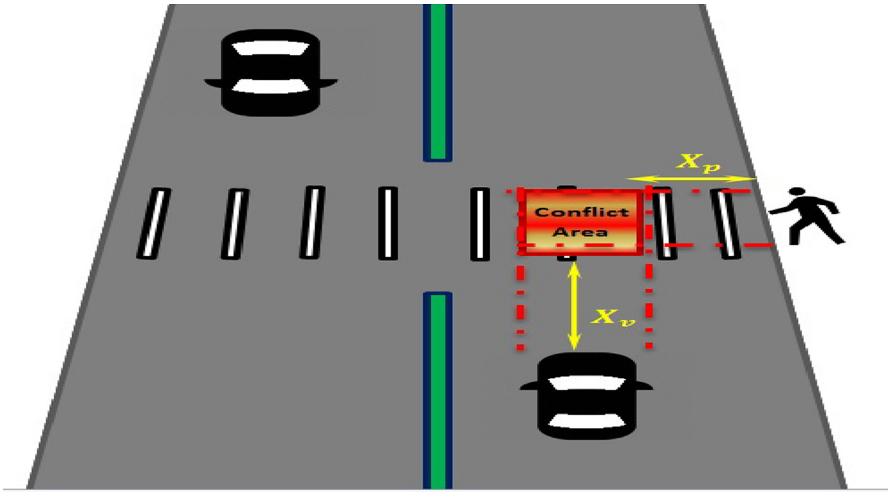

Fig. 1. Conflict situation between vehicle and pedestrian.

the last 20 years. According to the research by Hyden, there is a relationship between the severity of events and their frequency. Also, the study showed that conflict severity is detectable based on Conflicting Speed and Time to Accident rates.

- Time to Accident (TA): The time left from when the evasive action is taken until the collision would occur if the road users continued with unchanged speeds and directions. The TA value can be calculated based on the estimates of distances (d) and speed (v).
- Conflicting Speed (CS): Speed when the evasive action is taken.

Therefore, based on the fact that conflicts occur more frequently than collisions, valuable data can be collected for a traffic safety assessment over a short period (Hyden, 1987). The value of the strategy of this approach has the impetus for research on traffic safety research in many countries (Haperen et al., 2018; Laureshyn, de Goede, Saunier, & Fyhri, 2017; Sayed, Zaki, & Autey, 2013; Uzondu et al., 2018; L. Zheng, Ismail, & Meng, 2014). The present study tries to evaluate the vehicle–pedestrian conflicts in MCs and UMCs using the STCT to estimate the severity of conflicts. Determining levels of conflict severity along with identifying the safe maneuvers can be considered as the main inputs needed to prevent a collision with a pedestrian.

3.2. Binary logistic regression

In this study, a binary logistic regression model was employed for analysing DYB in the possibility of conflict. The purpose of the model is to anticipate the driver's likelihood of yielding based on collected data from NDS. When the driver encounters a pedestrian, the driver will either do yield (pass) or yield by making a decision based on various parameters. Binary logistic regression deals with situations in which the observed outcome for a dependent variable can have only two possible types. In this study, the logistic regression model identifies the role of influential variables on the probability of conflicts between V-V and V-P interactions, the general form of which is as follows:

$$\Pr(Y_i = 1|x) = \frac{e^{\text{logit}(p)}}{1 + e^{\text{logit}(p)}} \tag{1}$$

$$\text{logit}(p) = \ln\left(\frac{p}{1-p}\right) = \alpha + \beta_1 x_{1,i} + \beta_2 x_{2,i} + \cdots + \beta_k x_{k,i}, \quad i = 1, 2, \cdots, n$$

where (Y_i) is the probability of drivers' yielding when encountering pedestrian at the ith conflict, (x_k) is the independent variables affecting the driver's yielding and (β_k) is the independent variable coefficient.

4. Data

4.1. Study location

Studies on the urban roads in Babol county (population: 531,930) in Mazandaran province (population: about 3,283,582) were conducted in northern Iran (Fig. 2). According to the Iranian Legal Medicine Organization, Mazandaran is one of the provinces with a high accident rate for pedestrians in Iran (618 dead and 16,119 injured 2018), of which 32% is related to

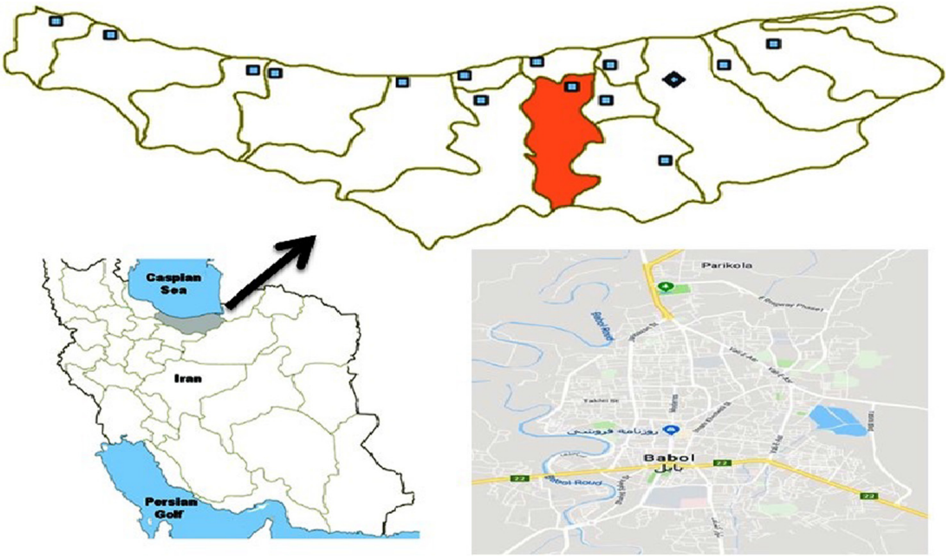

Fig. 2. The geographical location of Babol in Mazandaran Province, Iran.

pedestrian casualties (Iran forensic medicine, 2018). According to this report, about 50% of pedestrian casualties occurred on the urban roads of Babol city. In our previous study (Sheykhfard & Haghighi, 2019), the main causes of vehicle–pedestrian conflicts were determined at divided and undivided MCs in urban roads of Babol city.

Table 1 shows the geometric and traffic characteristics of UMCs and MCs on the roads that drivers traveled during the NDS. It can be seen that all the characteristics of the UMCs and MCs are similar. Therefore, this can help to accurately assess the differences in drivers' actions with respect to pedestrians in the two areas.

4.2. Data collection

NDS approach was used to accurately evaluate drivers' behaviors encountering pedestrians at MCs and UMCs in urban roads (Fig. 3). The participants were hired through local newspaper advertisements and cooperation requests in the traffic research laboratory at the Babol Noshirvani University of Technology. As a result, 52 participants (30 men, 22 women; 18–50 years; having valid driving license with an average of 2.9 years and an average distance travelled of 5500 km per year) accepted to participate in this research. All participants had a normal or corrected-to-normal vision and access to a reliable vehicle with liability insurance. Studies from April 2017 to April 2018 were conducted through NDS on the driving of participants to evaluate behavioral change among drivers throughout the year. Under the contract, the private vehicle of the participant was equipped with an in-vehicle video system (videography in motion), and the study lasted 7 days for each participant. In other words, a set of driving behaviors was recorded by a video camera during a week on different routes daily. On average, each participant was driving for about 90 min daily. Also, during the experiment, each participant drove about 495 km. The maximum distance traveled for one participant was about 885 km, while the minimum distance was about 205 km. Finally, by examining the films frame by frame using the Tracker software, 1348 vehicle–pedestrian conflicts were identified during the driving of participants in their daily routes. Of the 1348 vehicle–pedestrian conflicts identified in different urban roads, 956 conflicts were recorded in the UMCs and 392 conflicts in the MCs.

Table 1
Geometric and traffic characteristics of UMCs and MCs.

Characteristics	Unmarked Crosswalks	Marked Crosswalks
Crossing type	Uncontrolled crossing	Uncontrolled crossing
Crosswalk Markings	None	High visibility
Posted speed limit	40 km/hr.	40 km/hr.
Total of lanes	2 + median	2 + median
Direction of traffic	Two-way (3.65 m per lane)	Two-way (3.65 m per lane)

Fig. 3. The pictures of some participants in the NDS approach.

5. Result

5.1. Descriptive statistics of behaviors of pedestrians crossing and driver yielding

A descriptive analysis of these variables was conducted during the study of recorded films through the NDS of the participants. Based on the data, the number of conflicts in the UMCs was approximately 2.5 times the number of conflicts in the MCs (956 vs 392). As shown in Fig. 4, out of 956 conflicts identified in UMCs, 687 (72%) occurred in areas that were at a distance from the intersections. This parameter was also recognized for MCs locations so that the number of conflicts having occurred in areas away from the intersection was greater than the near/at intersection locations (67% versus 33%). Therefore, the probability of the occurrence of conflicts, both in MCs locations and in UMCs locations in areas away from intersections, is about 2–3 times higher than near/at intersections. The reason for this may be due to the tendency of drivers to drive at high speeds between two intersections. On the other hand, since the participating drivers are familiar with the study roads, they are expected to be more likely to drive faster in areas away from intersections than intersections because of information on the location of the intersections. Also, in these areas, due to the lack of drivers' expectation of a sudden crossing of pedestrians in the UMCs locations, the number of conflicts caused is greater than conflicts in MCs locations (72% vs. 67%). Besides, hazardous crossing behaviors such as zigzag and diagonal path while crossing by pedestrian could lead to an incorrect judgment of drivers about the exact place and tracking of pedestrian crossings. This issue decreases the possibility of DYB because drivers cannot accurately identify pedestrians' crossing paths and, consequently, the PPC with pedestrians.

According to Fig. 4, these two types of crossing paths were observed in 89% (855 cases) and 81% (316 cases) of conflicts occurring in UMCs and MCs sites, respectively. According to the data extracted from the films recorded in the NDS, male pedestrians tend to cross in zigzag and diagonal more frequently in comparison to female pedestrians who chose a perpendicular path when crossing. In UMCs sites, out of 611 detected conflicts during zigzag crossing, 483 cases were recorded by male pedestrians, which was approximately 3.8 times higher than that of female pedestrians (128 cases). Out of 244 cases of crossing as the diagonal path in the UMCs route, 186 were for male pedestrians and 58 for female pedestrians. It is important to note that women crossed perpendicular through streets twice as much as men, which could be due to their tendencies of low-risk crossing behavior. In the MCs sites, the behavioral differences were recognized between the male and female pedestrians similar to those in UMCs sites. The male pedestrians were more likely to cross through a zigzag path (117 cases) or a diagonal path (79 cases), while women preferred to cross through a perpendicular path (49 cases). As regards the style of crossing, running is an aggressive behavior adopted by pedestrians. In the present study, the final model of drivers' yielding showed that drivers are unable to make a yielding maneuver when encountering pedestrians running on the road, and this could increase the likelihood of conflict. The analysis of the films showed that the major portion of the vehicle-to pedestrian conflict was the pedestrian running (for UMCs sites it was about 2.47 times more than walking; for MCs sites, it was about 1.65 times more than walking).

Further findings showed that among 681 conflicts in UMCs sites, male pedestrians were involved in 517 cases (76%), while only 164 cases (24%) were female pedestrians. In MCs sites, male pedestrians assumed a running street crossing style 2.34 times more frequently than female pedestrians (171 cases versus 73 cases). Also, based on the results of the data analysis, with the increase in the number of pedestrians who intended to cross the street as a group, the drivers' tendency to yield facing pedestrians increased. As shown in Fig. 4, more than half of the conflicts occurred when pedestrians crossed as individuals on the street. On the other hand, the likelihood of drivers yielding behavior increased when facing pedestrians in groups of two or more. In both MCs and UMCs sites, individual pedestrians cannot force drivers to yield. Regarding distracted behavior of pedestrians, about 65% of the conflicts were identified in the UMCs sites (622 cases) and about 61%

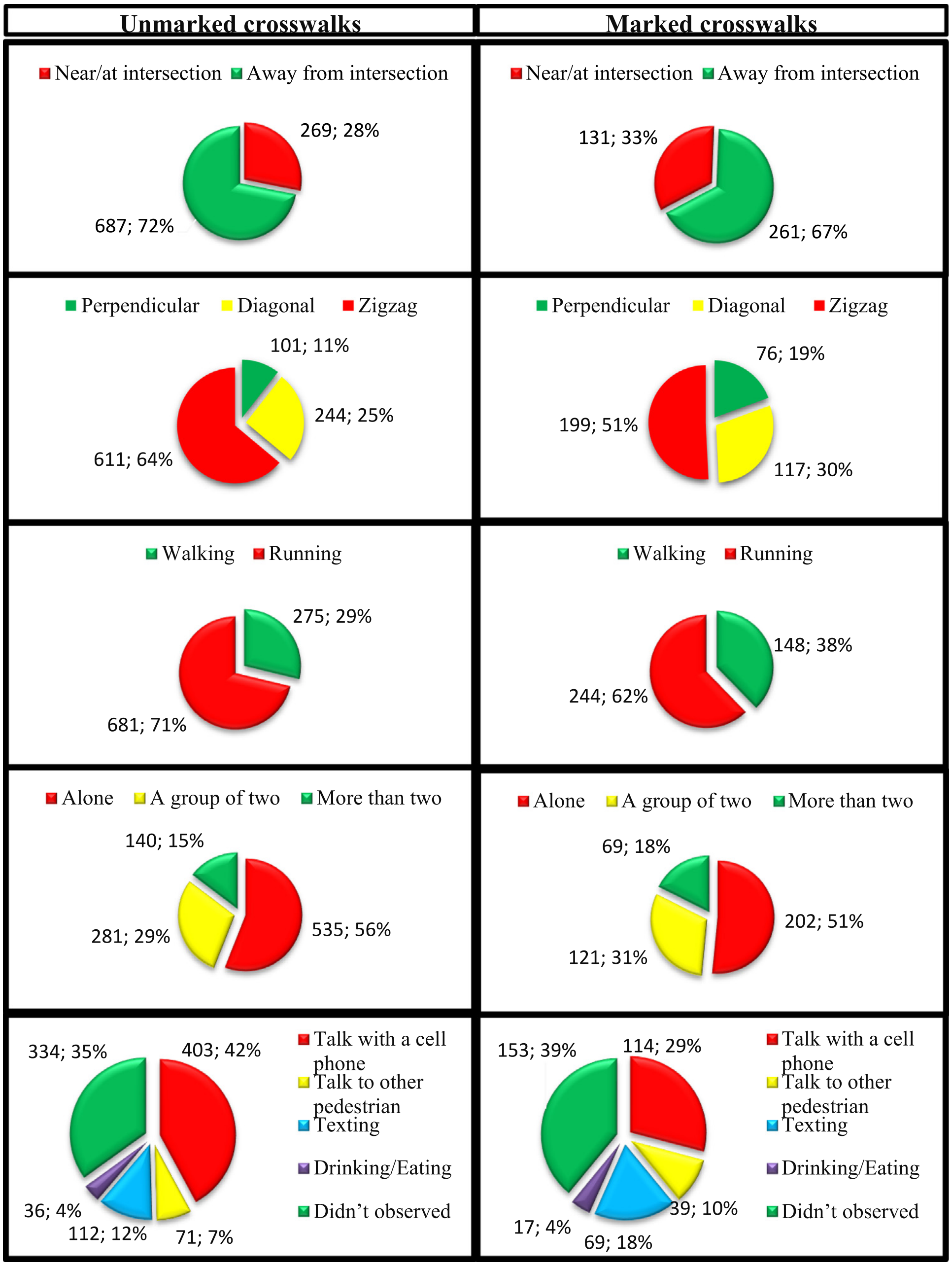

Fig. 4. Descriptive stats of conflicts concerning characteristics of pedestrian crossing behavior (the frequency and the percentage).

of the conflicts in the MCs sites (239 cases) when pedestrians talked on cell phones, talked together, texted, or ate/drank to the extent that they did not notice an approaching vehicle. According to Fig. 4, the impact of talking on cell phones is more than that of other distracting factors.

Fig. 5 shows the driver's yield rate at MCs and UMCs sites. According to Fig. 5, it is clear that with increasing the speed of the vehicle, the possibility of a driver's yield rate in both sites decreases. Despite this, to some speed limits, the yield rate is still as plausible. For example, data analysis shows that at speeds over 40 km/h (posted speed limit), the DYB can be high if the driver can detect and identify the pedestrian in a certain distance. In other words, both factors of speed and distance simultaneously affect the probability of DYB. Fig. 5 shows that in MCs sites, about 36% of the conflicts occurred when the driver detected a pedestrian at a distance of 40 m before the PPC (3.65 s) and, by making a maneuver prevented a collision with the pedestrian. Comparable situations in UMCs sites were approximately similar. In UMCs sites, only 11% of drivers who drove at a speed above the posted speed limit were able to yield, and in 89% of the cases, drivers continued route without any change on vehicle speed and direction.

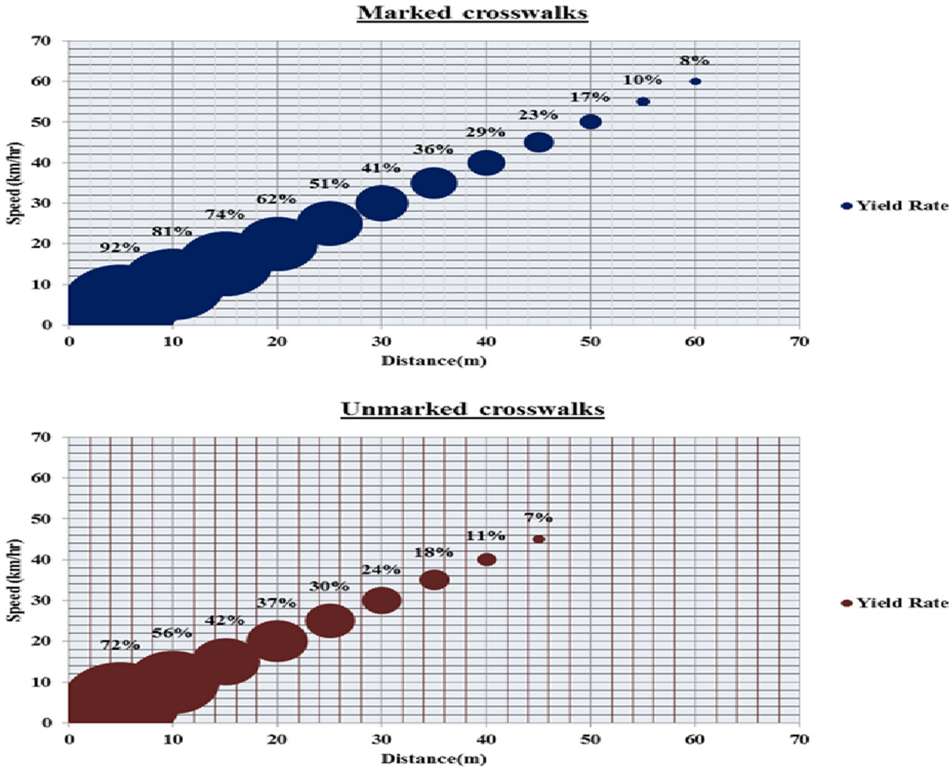

Fig. 5. Change of share of driver yielding behavior according to vehicle speed and distance to the pedestrian.

Finally, Fig. 5 emphasizes the need for pedestrian detection by the driver in both MCs and UMCs sites at different distances to increase the likelihood of DYB, and consequently to prevent collisions with pedestrians. Therefore, suitable detection of pedestrians in the area should be performed through driver factors or driver assistance to conduct DYB in the quickest way according to the traffic conditions of the road.

5.2. Model of driver yielding behavior

Table 2 shows possible independent variables that affect the DYB when faced with pedestrians. These variables were extracted by watching and analyzing the films recorded by the cameras to determine the model of the driver's yielding. Using the binary logistic regression model, the final model was determined based on the variables affecting driver behavior, as shown in Table 3. According to Table 3, only variables that were significant at 95% confidence level were involved in the final model. Therefore, driver gender, pedestrian gender, and driver distraction were excluded from the final model due to the low impact on the dependent variable of the model (p-value more than 5%). Other variables were identified effective on the DYB model (P-value less than 5%) and their relationship (straight: positive coefficient; inverse: negative coefficient) with

Table 2
Variable coding and definitions.

Variable	Definition	Type
Direction	0 for near/at intersection area; 1 for away from an intersection	Categorical
Speed	Speed of vehicle approaching conflict area, (km/hr.)	Continuous
Distance	The distance from the vehicle to pedestrian, (m)	Continuous
Crossing path	0 for perpendicular; 1 for diagonal; and 2 for zigzag	Categorical
Pedestrian gender	0 for female; 1 for male	Categorical
Crossing style	0 for walking; 1 for running	Categorical
Group Size	0 for alone; 1 for a group of two; and 2 for more than two	Categorical
Driver gender	0 for female; 1 for male	Categorical
Pedestrian distraction	0 for speaking using a cell phone; 1 for talking to other pedestrians; 2 for texting; 3 for drinking/eating; and 4 for no-factor	Categorical
Driver distraction	0 for attention to the road; 1 inattention to the road	Categorical

Table 3
Estimation binary model results of effective factors on p-value at 5% level of significance.

Variable		Coefficient		Std. Error		p-value	
		UMC	MC	UMC	MC	UMC	MC
Direction	Away from intersection	−0.881	−0.331	0.341	0.022	0.021	0.001
Speed		−1.425	−0.816	0.442	0.017	0.008	0.002
Distance		0.802	0.995	0.188	0.074	0.011	0.000
Crossing path	Diagonal	−0.359	−0.274	0.224	0.055	0.035	0.011
	Rolling	−0.609	−0.303	0.328	0.067	0.041	0.032
Crossing style	Running	−0.728	−0.407	0.318	0.008	0.015	0.010
Group Size	Alone	−0.445	−0.113	0.133	0.011	0.034	0.011
	More than two	0.529	0.758	0.201	0.027	0.030	0.019
Pedestrian distraction	Cell phone	−0.551	−0.192	0.089	0.041	0.005	0.014
	Talk	−0.237	−0.088	0.104	0.034	0.010	0.008
	Texting	−0.118	−0.029	0.137	0.019	0.008	0.004

the dependent variable of the model (probability of yield). Based on this, the negative coefficient of speed (Table 3) shows that with increasing vehicle speed, the driver's ability to perform any evasive maneuver (deceleration/acceleration/change the lane/or stop) is reduced. The negative coefficient of direction means that the probability of not yielding increases in distances further away from the intersection. The reason for this is the lack of drivers' prediction of the presence of pedestrians in these places.

Also, the results of the model show that running to cross and zigzag and diagonal crossing leave drivers with no time to perform their yielding, which subsequently increases the likelihood of vehicle–pedestrian collision. According to Table 3, the size of the pedestrian group of more than two people, as well as the large distance between the vehicle and the pedestrian, reduced the likelihood of conflicts between them. The reason for this was drivers' timely performance to yield. The negative coefficient of the pedestrian distraction variable in Table 3 shows that this parameter is one of the effective variables that increases the likelihood of conflict between vehicles and pedestrians when crossing.

To validate the model of DYB, the NDS of 10 new participants were reviewed in the studied roads. Data extracted in the obtained model were evaluated. A comparison of the results from the prediction by the model and the real observation showed that the model of DYB can predict correctly to about 89% of DYB. Also, the Hosmer- Lemeshow test (p-value) confirmed that the model was well-fitted.

5.3. Determining the conflict severity based on STCT

As discussed in Section 3.1, the STCT was proposed to evaluate traffic conflicts. Based on this technique, the nature of the conflicts and traffic accidents is similar, except that an evasive maneuver from at least one of the users of the road prevents conflict from being transformed into an accident. This technique is based on the speed of the vehicle and the time remained until the accident, which could determine the levels of conflict severity. Different levels of conflict severity were presented as a safety pyramid by Hyden (1987). Based on the pyramid, the lower part reflects the common events between road users that are safe and usually occur. Meanwhile, the top part consists of the most critical events such as accidents which is quite uncommon compared to the total number of the events.

In the present study, recorded films were reviewed several times to accurately determine the vehicle–pedestrian conflicts based on time to accident and the speed of conflict at the time of maneuver by one of the two users. The purpose was to identify the evasive maneuver that was initially undertaken by one of the two users to prevent a possible collision. After data extraction, 956 conflicts identified in UMCs and 392 conflicts identified in MCs areas were classified into 30 different levels by time to accident and conflicting speed. These 30 levels are based on the probability of conflict occurrence in 4 general levels: 1) Encounter; 2) Potential; 3) Slight, and 4) Serious (Fig. 6). Of the 956 conflicts identified in the UMCs area, 244 cases (25.5%) were in a group of encounter conflict, 219 cases (23%) in potential conflict, and 388 cases (40.5%) in slight conflict, and 105 cases (11%) were in serious conflict. The numbers of conflicts of the different levels in the MCs area in groups of encounter, potential, slight and serious were 149 cases (38%), 55 cases (14%), 121 cases (31%), and 67 cases (17%), respectively (Table 4).

5.3.1. Unmarked crossing area

Data analysis showed that during the majority of cases in the group of encounter conflicts, pedestrians are the key road user who have reduced the probability of conflict by performing some kind of evasive maneuver. In other words, in the group encounter (level of conflict severity: 0–10), 79% of the conflicts (193 cases) did not transform into accident by the safe maneuver of pedestrians. In these situations, pedestrians reacted by actions such as going back on the street, stopping, reducing or increasing the speed of walking, or running in the street. On the other hand, in 21% of the conflicts (51 cases), the drivers mostly performed evasive maneuver as deceleration and acceleration in time of detecting pedestrians on the road and considering the danger of possible collisions with them. Of these, DYB of drivers was recognized in 38 conflicts (29 cases

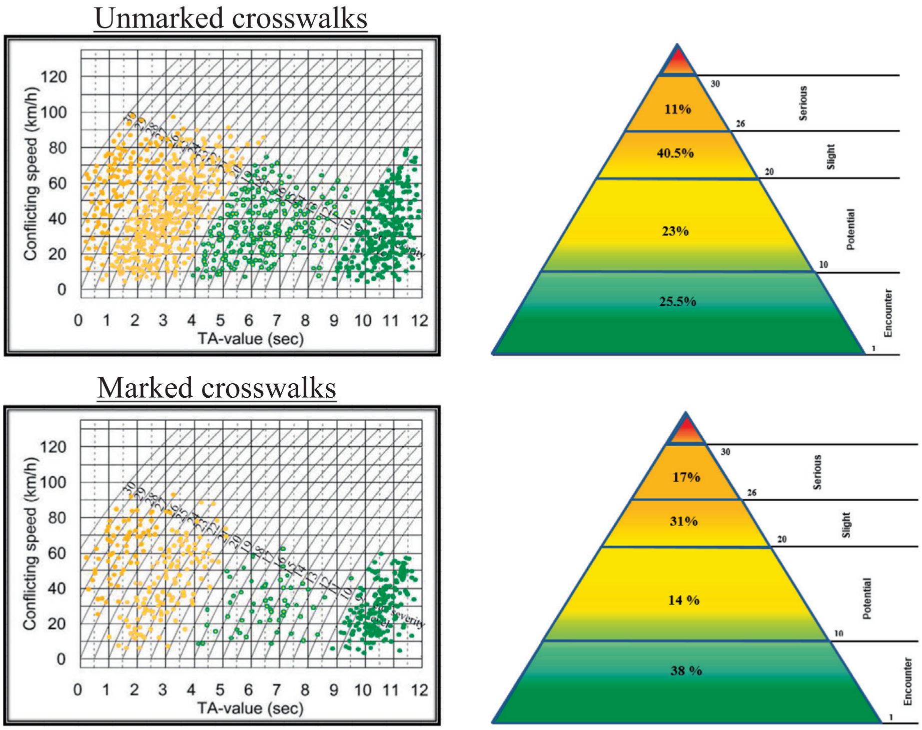

Fig. 6. Vehicle-pedestrian Conflicts classification based on severity levels.

for deceleration, 7 cases for acceleration, and 2 cases for changing the lane; See Table 4). Analysis of conflicts of the group of potential conflicts (level of conflict severity: 10–20) showed that the driver was the key factor in evasive maneuver behaviors at the time of conflicts. In 176 cases of the conflicts (80%), drivers attempted to prevent collisions with pedestrians mostly through a soft maneuver such as deceleration/acceleration. In 83 cases, drivers yielded to pedestrian through slowing down their vehicle. Out of 388 conflicts of the group of slight (level of conflict severity: 20–26), drivers in 334 cases (86%) showed both soft and harsh maneuver. More specifically, in 135 cases (40%) of the conflicts, the yielding behavior through changing the lane (as a harsh maneuver in 76 cases) and a decrease in speed (as a soft maneuver in 41 cases) led to the pedestrian crossing before the vehicle arriving to the PPC, while in other conflicts the drivers prevented the crossing of pedestrians by increasing vehicle speed (non-yielding in 29 cases; See Table 4). A total of 105 conflicts were in the group of serious (level of conflict severity: 26–30), of which 69 drivers tried suddenly to stop by a harsh maneuver, such as pressing the brake pedal. In fact, they suddenly braked as soon as they saw the pedestrian considering the possibility of a collision with the pedestrian, which, of course, did not stop the vehicle completely due to vehicle speed and time in some cases. In 50 cases, vehicle speed decreased to a minimum (less than the posted speed limit) after crossing the PPC. The behavior of pedestrians in these conflicts was going back or running in the street. In addition, in other 19 cases, the braking by drivers provided the opportunity to cross (yielding behavior).

5.3.2. Marked crossing area

The pattern of the occurrence of conflicts and evasive maneuvers by drivers and pedestrians was observed based on different levels of severity in MCs area, which was similar to those of UMCs area. During conflicts at the level of encounter, pedestrians were a major factor in avoiding collisions with approaching vehicles ($\frac{108}{149} = 72.4\%$). In conflicts at potential conflict level, drivers performed evasive maneuver through a soft maneuver at the time of the occurrence of 43 conflicts ($\frac{27}{43} = 0.63$), where in 14 cases drivers decelerate the vehicle. Assessment of 121 conflicts at the slight level showed that drivers made an avoidance action in 94 cases, including 28 soft-maneuvers (deceleration/acceleration) and 93 harsh-maneuver (changing the lane/stop). During 67 serious conflicts, drivers continued to harsh-maneuver (36 cases as stop, 12 cases as changing the lane) to avoid pedestrian collisions, which in 17 cases resulted in pedestrians crossing the street (yielding behavior). Further information on the maneuver of driver and pedestrian, as well as the number of driver maneuvers leading to yield, is shown in Table 4.

Table 4
The maneuver of drivers and pedestrians at different levels of conflict severity.

Level of conflict severity (Cases)	Who first performs an evasive maneuver?				Type of driver maneuver							
	UMCs area		MCs area		UMCs area				MCs area			
	Driver	Pedestrian	Driver	Pedestrian	Soft		Harsh		Soft		Harsh	
					Deceleration	Acceleration	Changing the lane	Stop	Deceleration	Acceleration	Changing the lane	Stop
Encounter	51	193	41	108	38 (29*)	11 (7)	2 (2)	0 (0)	26 (21)	11 (7)	3 (3)	1 (1)
Potential	176	43	43	12	107 (83)	54 (17)	11 (7)	4 (3)	15 (12)	12 (6)	9 (5)	7 (6)
Slight	334	54	94	27	113 (41)	35 (6)	163 (76)	23 (12)	16 (14)	12 (2)	46 (19)	20 (13)
Serious	91	14	59	8	7 (0)	2 (0)	13 (5)	69 (19)	8 (0)	3 (0)	12 (5)	36 (12)

* Numbers in parentheses indicate the numbers of cases that the driver maneuver has led to pedestrian crossing (i.e. driver yield).

6. Discussion about comparing conflict patterns in UMCs and MCs

Conflict patterns in both areas can be compared based on two different aspects:

- Model of DYB
- Evasive maneuver

As discussed in Section 5.2, the variables affecting the model of DYB were similar in both areas. According to Table 3, the variables of direction, speed, distance, crossing path, crossing style, group size, and pedestrian distraction had the same effect (whether positive or negative) on driver decision (to yield or not yield) in both areas. The only difference between the models is the beta coefficients (size of the effect of the variable) of the variables. The effect of variables speed, distance and group size on the safety of pedestrian crossing has been reported in previous studies in UMCs (Y. Zheng, Chase, Elefteriadou, Schroeder, & Sisiopiku, 2015; Zhuang & Changxu, 2013; Zhuang & Wu, 2011). Also, some previous studies in MCs reported the speed, crossing path, pedestrian distraction, and distance between vehicle and pedestrians as influential factors on pedestrian safety (Brosseau et al., 2013; Chen et al., 2017; Hunter et al., 2015; Kadali & Vedagiri, 2013; Wu & Xu, 2017). The present study showed that conflict patterns between vehicle and pedestrians in UMCs and MCs are similar, although the probability of occurrence of conflicts in UMCs area is higher than that of the MCs area.

Furthermore, Table 3 indicated that the probability of occurrence of non-yielding in UMCs area is higher than MCs based on the same variables. For comparison of behavioral characteristics, variables such as pedestrian distraction and size of the group can reveal the difference in two areas. According to Fig. 4, in MCs area, the probability of distraction of pedestrians being engaged with a secondary task during the crossing, such as talking on a cell phone, was less than that in the UMCs area, which increased the safety of pedestrian crossing in MCs area (increasing the likelihood of yielding according to Table 3). However, other studies (Herms, 1972; Zegeer et al., 2001) which used pedestrian accident databases reported that the accident rate is higher in MCs compared to UMCs. The misinterpretation about the environmental conditions by pedestrians and their misjudgment towards DYB are possible explanations. In other words, pedestrians made high-risk aggressive crossing behavior, assuming that drivers would show more yielding behavior when they approached the MCs. As result, the aggressive behavior increased the probability of accident. Pedestrian's aggressive behaviors such as not paying attention to approaching vehicles, as well as running on the road, have been also reported in other studies as causes of vehicle–pedestrian conflict and accidents (Habibovic et al., 2013; Lin et al., 2018; Serag. , 2014; Wu & Xu, 2017; Zhuang & Changxu, 2013).

Additionally, in MCs area, pedestrians tended to pass as a group on streets more than pedestrians in UMCs, which led to an increased probability of DYB in MCs area compared to UMCs area (Table 3). In Table 3 and Fig. 5, the probability of DYB was presented on two variables: vehicle speed and distance to the pedestrian. Despite the similarity of the type of relationship between these two variables with the probability of driver yielding in both areas (negative coefficient for speed, and positive coefficient for distance), drivers in the UMC area tended to drive at higher speeds, which also reduced the time needed for drivers to decide when the pedestrian was detected (i.e. due to shorter distance). As a result, the probability of DYB in UMCs area was lower than that of MCs. The investigation of evasive maneuvers at different levels of severity of conflicts pointed out that behavioral patterns among drivers and pedestrians in both sites are significantly similar. As mentioned in Table 4, at low levels of conflicts, pedestrians are often the key users in preventing a conflict which might turn into a collision. Significantly, in these situations drivers tried to prevent collision with pedestrians through soft maneuvers such as increasing or decreasing the speed of the vehicle, as a result of which the possibility of safe crossing by pedestrians in several cases enhanced on both sites. Nevertheless, the most important difference between evasive maneuvers in both areas is related to the type of action taken by drivers at speeds and different distances to pedestrians. Given that drivers in UMCs area were frequently driving with higher speed than in MCs area, they were more willing to perform a harsh maneuver such as changing lane or trying to stop compared to soft maneuvers in UMCs routes when encountering pedestrians. Table 4 suggests that at high levels of conflicts, drivers who are driving in MCs routes are less likely to make a harsh maneuver when encountering pedestrians than drivers in UMCs routes. The main reason was that they lowered speed, which provided sufficient time to identify pedestrians at further distances. It helped them to maintain control over driving and avoid systematic harsh maneuvers.

7. Conclusions and future research

This study evaluated the driver yielding behavior (DYB) during encounters with pedestrians in UMCs and MCs areas. The purpose of this study was to determine the patterns of vehicle–pedestrian conflicts and also to determine the behavioral modeling of driver yielding in the two areas. The naturalistic driving study (NDS) was conducted for 52 participants (7 days for each participant) and the data were extracted by examining the films recorded through the cameras installed inside the vehicle. First, the model of DYB in both areas was determined based on significant variables. The model showed the impact of the behaviors of drivers and pedestrians on the probability of the DYB, and consequently to the occurrence of conflicts. Aggressive crossing behaviors by pedestrians such as running and zigzag and diagonal paths, as well as high-risk behaviors of drivers such as high-speed driving, increased the probability of conflicts.

Then, the conflicts in both areas were analyzed based on SMoS. The data were evaluated using the Swedish traffic conflict technique (STCT) based on conflicting speed and time to accident at the possible point of collision (PPC). Conflict patterns based on the STCT showed that evasive maneuvers by road users at the moment of conflicts prevent collisions between vehicle and pedestrian; the structure of these maneuvers is similar in both UMCs and MCs areas. At low levels of conflict severity, pedestrians are the main factor in preventing conflict-to-accident transmission, while with increasing levels of conflict severity, drivers play a key role in yielding behaviors or controlling driving to reduce the probability of collisions. Drivers by making soft maneuvers (deceleration or acceleration) and harsh maneuvers (changing the lane or stopping by extreme braking) react according to the conditions on road at different levels of conflict severity.

In general, the findings of this study showed that the causal patterns of conflicts, as well as patterns of evasive maneuvers by drivers and pedestrians, are similar in both areas, although the probability of the occurrence of conflicts in UMCs area is higher than that in the MCs area. Also, the findings of this study show that during conflicts with high-levels of severity, the driver plays a key role in reducing the probability of collision with pedestrians through yielding behaviors. Therefore, the improved design of the Advanced Driver-Assistance System (ADAS) to identify the risk of the pedestrian accident seems necessary. It is suggested that future research focus on designing an intelligent algorithm that would assist the driver in critical situations when facing pedestrians. This algorithm, based on the behaviors of drivers and pedestrians, could estimate the risk of collision and make the best maneuver for the driver.

Finally, although the NDS gave insightful results about driver and pedestrian conflicts on the routes in the present study, it has some limitations in terms of data collection. For example, the behavior of pedestrians involved in conflicts could not be thoroughly assessed before the instrumented vehicle approached the conflict zone. Variables such as the waiting time for finding a safe gap, as well as the number of failed attempts to cross the road, may affect pedestrian behavior. Consequently, simultaneous use of fixed videography with the on-road NDS may lead better results on the conflict between drivers and pedestrians.

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