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Review Article

# Review and assessment of different perspectives of vehicle-pedestrian conflicts and crashes: Passive and active analysis approaches

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## HIGHLIGHTS

- 169 studies were categorized into two different approaches, active and passive.
- Passive studies investigate the causes of accidents from the perspective of human, environmental/road, and traffic factors.
- Based on active studies, the risky behaviour could lead to driving errors, lapse, intentional and unintentional violations.
- The attitude of drivers and pedestrians significantly reflects their behavior in real conditions.
- Risk perception and decision-making processes are the most important bond between the attitude and behavior of road users.

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ABSTRACT

The importance of investigating pedestrian safety has been evaluated repeatedly in safety studies. The present study attempts to evaluate the various methods used by previous researchers in a hierarchical process, to determine the characteristics, advantages, and limitations of each method. Two general analysis approaches (passive and active) were taken into account to categorize 169 previous types of research. In the passive approach, the studied methods were those based on crash databases, questionnaires, and post-crash field observation data; while, in the active approach, the studied methods were those based on driving simulations and videography. The result of the passive approach reveals that road users' features and road characteristics (crash database studies), and error, lapses, intentional and unintentional violations (questionnaire studies) by them were among the most important causes of crashes and conflicts. Furthermore, road users' distractions also reported a set of factors affecting the possibility of conflicts and crashes based on post-crash field observation studies. Also, results of the active approach showed that risky behaviors are the most important factor in threatening pedestrian safety such as unauthorized speeding, non-compliance with traffic law, unauthorized overtaking by drivers, and illegal crossing. Furthermore, risk perception and decision-making processes are the most

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important bond between the attitude and behavior of road users in dangerous driving situations. Examining studies through passive approach would lead to identifying the causes of crashes, recognizing the attitude of road users towards safety, and determining road users' behavioral patterns in certain situations, while the active approach has led to a more detailed understanding of behaviors and attitudes of road users. The inference of the findings obtained in this study will lead to a better understanding of the behavior of road users for studies on advanced driving assistance systems (ADAS).


## 1. Introduction

With the advancements of technology and the increasing growth of motor vehicle production, which results in increased traffic congestion and increased air pollution, the health of the society has been taken into account more than ever by the global community. Applying different non-motorized transportation modes, such as walking, cycling, etc., is one of the approaches adopted in this regard. Today, walking has become one of the most important modes of transportation around the world, but pedestrian safety, especially while crossing the street, is one of the most important challenges for traffic safety researchers. In addition to the social, cultural, and other consequences, the casualties and injuries in pedestrian crashes bring about significant economic costs in each country each year. According to the latest reports of the international organizations associated with road safety (OECD, 2017; WHO, 2018), pedestrians are the most vulnerable group of road users, accounting for a significant share of road crashes. According to the reports, an average of 23% of the world's annual 1.35 million casualties is pedestrians. On the other hand, the number of casualties is not the same in different countries. Middle-income countries, despite their 59% share of the total number of motor vehicles worldwide, account for about 80% of road fatalities (OECD, 2017; WHO, 2018). For example, in this report, Iran, with a population of about 80 million, is one of the middle-income countries with an average of 20.5 fatalities per 100,000 inhabitants, which is above the global average. Also, the loss of road crashes in Iran is estimated at 6.5% of GDP. According to the reports, the share of pedestrians in road crashes varies from 14% to 40% in different countries. For example, pedestrians make up about 27% of road crash casualties in Europe, while in the East Asian countries the rate is only 14%. On the other hand, pedestrians account for about 40% of road crash casualties in Africa-the highest rate of casualties among continents. Pedestrian casualties in the Oceania and US continents have been reported at 22%. The factors that cause crashes are identified based on three main groups of human factor, vehicle factor, and road/environmental factor. As the most important factor in crashes, the human factor results from the human errors due to improper performance by road users (drivers, motorcyclists, pedestrians, etc.) in complex situations.

Different behavioral characteristics and physiological abilities of road users are one of the main reasons for the differences in their performance (Bakhtiari et al., 2019; Fournier et al., 2020; Leonardi et al., 2020; Papadimitriou et al., 2013, 2016; Sheykhfard et al., 2020; Wu and Xu, 2017). On the other hand, factors such as defects of the vehicle or the inherent capabilities of the vehicle as well as the weather or the geometry/pavement conditions can increase the risk of a crash (Sheykhfard et al., 2021a, b; Xu et al., 2018). These factors can cause crashes by interacting with each other. In other words, the low performance of each of these factors causes instability in the interactive cycle between the other factors and ultimately increases the risk of crashes. In general, given the important role of the human factor in this cycle, evaluating the behavior of road users to improve their performance can play a major role in improving the traffic safety of routes and consequently reducing the risk of crashes. A pedestrian crash is one of the most common modes of road crashes due to the considerable vulnerability of pedestrians because of a lack of energy-depleting means in the collision, which has always caused human and financial damage to communities. So far, behavioral studies of road users, especially motorists and pedestrians, have been performed around the world, although the number of behavioral studies on drivers is far less than those performed on pedestrians (Shi et al., 2016; Zhuang and Wu, 2014). These studies have used a variety of methods to measure and assess the safety of traffic and pedestrian crashes. Of course, using data from the crash databases has been traditionally the most important analytical approach. Although the use of data analysis, as one of the passive instruments, has played an important role in achieving the goals of traffic safety improvement research, there are several reasons for the high inaccuracy of these statistics (Larsen, 2004; Laureshyn et al., 2010). The details of the crash environment before the collision and the physical characteristics of the route are some of the major factors that are not recorded in the crash databases. Meanwhile, investigating the factors and conditions of all groups affecting crashes (human, environment, road, and vehicle) can lead to better analysis and thus higher accuracy of research results.

In contrast, the use of active tools, such as the study of natural driving behavior, has become one of the common methods of traffic safety studies in recent years. This

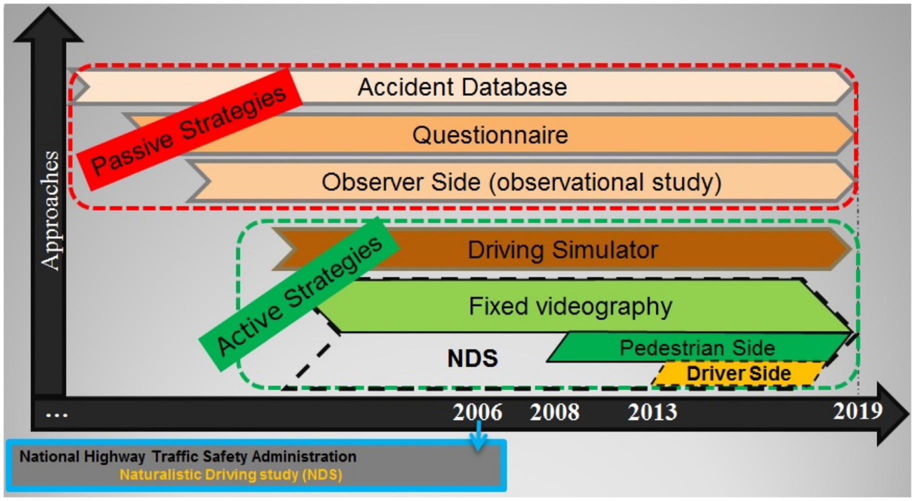


**Fig. 1 – Approaches of pedestrian crossing safety analysis in previous studies.**

analytical approach allows accurate examination of traffic flow with greater details. In other words, the use of cameras or videography of the traffic flow results in a more detailed evaluation and also allows frequent observation of the behavioral characteristics of road users before, during, and after crashes (Jonasson and Rootzén, 2014; Sullivan et al., 2015). By observing the recorded videos, the researchers extract the required data and analyze the safety risk of the study routes using a variety of methods. It should be noted that it is possible to collect microdata of the traffic, including successful attempts, traffic direction, and kinematics information of road users at different moments through videography analysis. Finally, using the active tools, behavioral studies of drivers and pedestrians can address pedestrian safety not from the perspective of a collision, but the perspective of the likelihood of conflict between them. Such an approach can provide a framework for improving pedestrian safety when crossing the street and, ultimately, adopting intelligent methods to prevent pedestrian crashes. One of the objectives of any community transportation safety system is to use the tools needed to eliminate or reduce factors that increase the risk of crashes. Various probabilistic models that are used to identify influencing factors as well as predict the conditions of crashes are special methods to improve the safety of traffic flow (Araar and el Tayeb, 2013). Investigating traffic flow conditions and the behavioral characteristics of road users is a powerful tool to better understand the complex conditions that arise between drivers and pedestrians. In general, the risk of a crash could be considered as a function of the risk of the crash and the severity of its consequences. In other words, the conditions of drivers and pedestrians when encountering each other, if they are likely to collide, could indicate the causal pattern of the risk of crashes between them. Determination of the causal patterns of crash risk through indicators and techniques of traffic conflict is a major step toward in identifying high-risk pedestrian-related crash conditions.

It should be noted that traffic conflict is defined as an observable situation where two or more road users come together at the same time and place if their initial movements are unchanged (Davis et al., 2011). Accordingly, high-intensity traffic conflict can be a risk factor for crashes. Concerning pedestrian crashes, taking into account the role of the driver and pedestrian as two important human factors involved in the conflict, their behavior, and interactions at different times should be evaluated. Identifying their functional models and analyzing the corresponding data could provide the data required as input for the traffic conflict analysis. This approach can ultimately indicate the risk of pedestrian crashes as an output for the traffic conflict analysis between the vehicle and the pedestrian. Considering the important role of the human factor in crash occurrence (OECD, 2017; WHO, 2018), evaluating the behavior of road users (drivers and pedestrians) to improve their functional status can play a major role in improving the traffic safety conditions of the routes and consequently reducing the risk of crashes.

The present study attempted to determine the role of drivers' behavioral errors as well as pedestrians through the investigation of studies on the causes of crashes or conflict between them. The main objectives are an extensive examination of the approaches used in these studies to determine their strengths and limitations, as well as evaluating the findings of this research on the vehicle-pedestrian conflicts and crashes. This study consists of four sections. In the second section, the application of passive approaches is evaluated and the studies accomplished in this field are discussed by different data collection methods. The third section focuses on the evaluation of the active approaches. In this section, different methods of data collection are analyzed, and also the findings of studies in this field are addressed. The section will be the conclusion section, which will summarize the research findings.

## 2. Review of passive approaches

Several studies have been made in recent years using different methods to investigate the collection of factors that lead to pedestrian crashes. In Fig. 1, these factors are tentatively

**Table 1 – Studies based on a crash databases.**

| Reference | Study subject (country) | Variable | |
|---|---|---|---|
| | | Independent | Dependent |
| Almasi et al. (2021) | Analysis of the surrogate measures related to pedestrian crash exposure in urban roads (Iran) | Sociodemographic characteristics, land use, and geometric characteristics of the network | Pedestrian crash exposure |
| Samerei et al. (2021) | Modelling bus-pedestrian crash severity in the state of Victoria (Australia) | Human, roadway, and environmental factor | Pedestrian fatality |
| Värnild et al. (2020) | Examine pedestrian crash in urban road (Sweden) | Pedestrian body | Injury severity |
| Thomas et al. (2020) | Epidemiology of pedestrian fatalities (USA) | Alcohol and drug | Pedestrian fatality |
| Wang et al. (2019) | Crash severity analysis (China) | Human damage and case fatality rate | Crash severity |
| Huang et al. (2018) | Pedestrian head injuries (China) | Physical parameter | Head injury severity |
| Mohamed and Bromfield (2017) | Young drivers' behavior (Saudi Arabia) | Attitudes, driving behaviors, and crash involvement | Crash risk |
| Verzosa and Miles (2016) | The severity of road crash (Philippines) | Pedestrian and environmental characteristic | Crash severity |
| Etehad et al. (2015) | Impact of road traffic crashes on the elderly (Iran) | Age | Crash risk |
| Khattak and Tung (2015) | The severity of pedestrian crashes at highway-rail grade crossings (USA) | Investigation of the role of traffic parameters and geometrical and environmental conditions of pedestrian on pedestrian crash | Crash severity |
| Nowakowska (2014) | Evaluation of threat for pedestrian crash (Poland) | Drug and alcohol | Crash severity |
| Araar and el Tayeb (2013) | Analyzing road traffic crash (United Arab Emirates) | Age and gender of pedestrian, driving skill, type of vehicle, alcohol and drug use, weather and route lighting | Crash causes |
| Theofilatos and Efthymiou (2012) | Pedestrians' crash patterns (Greece) | Personal attributes, as well as other recorded characteristics of the crash | Crash severity |
| Sullivan and Flannagan (2011) | Differences in the geometry of pedestrian crash (USA) | Daylight or dark condition | Crash risk |
| Kong and Yang (2010) | Pedestrian casualty risk (China) | Pedestrian's age and vehicle's speed | Casualty risk |
| Wanvik (2009) | Effect of road lighting on crash (Netherlands) | Road lighting condition | Crash risk |
| Kim et al. (2008) | Driver and pedestrian fault (USA) | Human, temporal, roadway, and environmental factor | Crash risk |
| Sze and Wong (2007) | Model for pedestrian injury severity (China) | Pedestrian behavior, traffic congestion, and junction type | Crash risk |
| Al-Madani and Al-Janahi (2006) | Analyze pedestrian injury crash (Bahrain) | Type of the crash, gender, age, nationality, and educational background of the victim | Crash risk |
| Lee and Abdel-Aty (2005) | Analysis of vehicle-pedestrian crashes at intersection (USA) | Drivers and pedestrians, and traffic and environmental characteristic | Crash cause |
| Ballesteros et al. (2004) | Pedestrian injury (USA) | Pedestrian and traffic characteristic | Crash severity |
| Zajac and Ivan (2003) | Effect of roadway and area type features on injury severity of pedestrian crash | Environmental characteristic | Crash severity |
| Al-Ghamdi (2002) | Pedestrian-vehicle crash (Saudi Arabia) | Factors recorded in the crash database | Crash cause |
| Simončič (2001) | Analyze road traffic crash (Slovenia) | Drivers and pedestrians, and traffic and environmental characteristic | Crash risk |
| Abdel-Aty and Abdelwahab (2000) | Examining the differences in an alcohol-related crash (USA) | Alcohol consumption | Crash risk |

classified as per the purposes of our review. As illustrated in the figure, the factors are divided into passive and active approaches, which will be discussed in more detail below, and their advantages and disadvantages are interpreted from different angles. In this paper, it has been attempted to evaluate pedestrian safety through the investigation of 169 previous studies. To this aim, a literature review in the scientific database Scopus including both journal papers and conference proceedings were conducted in February 2020. To describe the current status, only papers published after 2000 were studied. The initial idea for selecting papers was to use the included terms “pedestrian” or a combination of the terms “pedestrian” and “crash database”, “driving simulator”, “observational study” or “naturalistic driving study” in the category “title, abstract or keywords”.

Generally, the passive approach is a method to investigate the causes of crashes by examining crash databases or surveying the community. Investigating environmental conditions and the route after a crash (field studies) is also another approach.

### 2.1. Methods

#### 2.1.1. *Pedestrian safety analysis through the crash database*

One of the safety analysis methods in the passive approach that has a relatively long history is to identify crash-prone sites by using crash databases and statistical models (Scott and Gray, 2007). In other words, if an unusually large number of crashes occur at a particular site, it indicates that it is likely that the road design or traffic system operation could not provide the necessary safety (Park et al., 2010). Most research on traffic safety has been based on the passive approaches or statistics of road traffic crashes, and they can be used, for example, in developing crash forecasting models and investigating crash severity (Park et al., 2010; WHO, 2018). Although crash databases have long been recognized as a relatively robust collection of data for evaluating the cause of a crash throughout the world, it can be said that the results of the final model will greatly depend on the accuracy of the data provided in a crash report by the police officers and other relevant experts. Failure to record accurate data, whether inadvertently or intentionally, can lead to inaccurate results in crash prediction models. For example, to increase the accuracy of the data in crash databases of Seoul, South Korea, Chung and Chang (2015) studied the crash through two instruments of police reports and data collected from a vehicle's black box camera. The study was performed on several variables such as vehicle speed in the crash, location of the crash, the ultimate cause of the crash, and other geometrical, traffic, environmental, and atmospheric conditions. Although the results showed the efficiency of data from crash databases, there were some differences in some variables. The analysis of the results showed that the use of crash databases can lead to an inaccuracy in measuring the vehicle speed during the crash, the location of the crash, and the time of the crash. An 85 m difference in the location of the crash, a 9 km/h difference in the speed of the vehicle, and a time difference of about 19 min indicated a comparative difference between the two methods in their research design (Chung and Chang, 2015). Table 1 shows some of the studies conducted through crash databases in which researchers have used crash data to investigate the causes of pedestrian crashes. Although in recent studies, researchers have attempted to better and more accurately evaluate crashes, they still use the data recorded in the crash database, the accuracy of which cannot be ensured. Therefore, unreliability is a major challenge when examining pedestrian crashes through crash databases, thereby reducing the level of confidence of this approach. In general, there are two general policies for presenting all table in the present research: frequency and history of the approach. The evaluation of previous studies and various references showed a relatively straightforward hierarchical trend in each of passive approaches. On the other hand, considering the diversity of sources for each of the approaches, the studies have been presented based on the number of similar topics and their publication year.

#### 2.1.2. *Safety analysis through questionnaire data*

Despite the important role of the human factor in road crashes, few studies have been performed on human error while driving. It seems that examining the driving performance, wrong decision-making, and, consequently, an increase in the likelihood of a crash, can lead to the determination of mental patterns to be used in driver training centers and other centers related to enhancing the quality of driving. Meanwhile, over the past few years, studies have been conducted on the psychological characteristics of individuals that have led to inaccurate analyses of traffic flow environments. The benefit of using survey data using crash history is that it is possible to better examine the various dimensions regarding drivers and other road users involved in crashes. Reporting information on their behavioral and performance conditions and other issues in the questionnaires will lead to an improvement in the quality of crash data. On the other hand, using surveys, it is possible to evaluate events such as conflicts, and road users could provide researchers with information on issues that increase the potential for crashes. Despite the improvement in data obtained on road users through questionnaires, still, insufficient data were available on road conditions or road users. Although self-reports of road users was a major improvement in gathering information, important information on crash situations is lost due to various reasons such as inaccuracy in reports or insufficient information. Besides, people are often biased when they report on their own experiences. This phenomenon is known as social desirability bias, in that they may respond in a socially acceptable way. Many individuals are either consciously or unconsciously influenced by “social desirability”: that is, they are more likely to report experiences that are considered to be socially acceptable or preferred (Brener et al., 2003; Demetriou et al., 2015; Leeuw et al., 2008). For this reason, regarding a survey on driving behavior, people might not tend to report their violations. Therefore, post-crash field observation was another type of passive approach used by researchers to complement the methods of using crash databases and questionnaires. The features of this approach are discussed below. Some of the questionnaires-based studies on the causes of pedestrian crashes are presented in Table 2.

**Table 2 – Studies based on a questionnaires.**

| Reference | Study subject (country) | Variable | |
|---|---|---|---|
| | | Independent | Dependent |
| Dinh et al. (2020) | Attitudes towards traffic safety (Vietnam) | Risk perceptions and pedestrian behaviors in Vietnam | Risk perception |
| McIlroy et al. (2019) | Validation of a pedestrian behaviour questionnaire (United Kingdom) | Pedestrian behaviour | Risky behavior |
| Rolison et al. (2018) | Investigating the set of human error (United Kingdom) | Human error | Risky behavior |
| Deb et al. (2017) | Develop and validate a self-reporting pedestrian behavior questionnaire (USA) | Pedestrian behavior | Risky behavior |
| Ram and Chand (2016) | Investigating a set of factors that lead to inappropriate behavior and behavior of driver (India) | A set of Indian driver's erroneou behaviors and practice | Risky behavior |
| Papadimitriou et al. (2013) | Identify patterns of pedestrian attitudes, perceptions, and behavior in Europe (Greece) | Pedestrian attitude | Risk perception |
| Taubman-Ben-Ari and Shay (2012) | Associations between the risky behaviors of drivers and pedestrians (Israel) | Risky driver and pedestrian behavior | Risky behavior |
| Stavrinos et al. (2011) | Distracted walking (USA) | Distraction factor | Risky behavior |
| Zhou and Horrey (2010) | Pedestrian intention to cross the road (China) | Adolescent pedestrians' behavioral | Pedestrian decision |
| Schwebel et al. (2009) | The influence of carrying a backpack (USA) | Backpack vs. no backpack | Pedestrian decision |
| Bernhoft and Carstensen (2008) | Preferences and behavior of pedestrian (Denmark) | Age and gender | Pedestrian decision |
| Holland and Hill (2007) | Age, gender, and driver status on pedestrians' intentions to cross (United Kingdom) | Age, gender, and driver status | Pedestrian decision |
| Yang et al. (2006) | Pedestrians' road crossing behavior (China) | States of some external factors like a policeman, vehicle flow, and other pedestrians' behavior | Pedestrian decision |
| Lam (2005) | Parental risk perceptions of childhood pedestrian (Australia) | Cultural factor | Pedestrian decision |
| Moyano (2002) | Pedestrians' attitudes towards traffic violation (Chile) | Pedestrian characteristic | Risk perception |
| Lam (2001) | Parental safe road behavior (Australia) | The region, age, country of origin, non-English speaking education | Risk perception |
| Yagil (2000) | Pedestrian beliefs related to the road crossing (Israel) | Traffic volume, physical conditions, pedestrian mood | Pedestrian decision |

#### 2.1.3. *Safety analysis through post-crash field observation*

Behavioral studies of vehicle drivers are one of the relatively recent research approaches to road traffic safety. Although no general factor could be mentioned as the cause of a crash, one factor may be more pronounced. Among the causes and errors related to the human factor in a crash, the driver's behavior can significantly lead to a crash. In the case of pedestrian crashes, the drivers and pedestrians have a mutual interaction that may lead to the collision. For this reason, the deployment of monitoring teams on some sites aiming at observing the road users may be considered as a positive approach. In most studies using this method, researchers have sought to gather comprehensive information on the behavior and performance of road users as well as the conditions of the road by deploying their monitoring teams on the routes that, according to crash statistics, are considered crash-prone sites. Table 3 presents several studies using this approach.

The most important features of the studies in the passive approach could be considered as the main structure of each of the related data collection methods. For example, in studies conducted by the crash database, the common objective of the study is to investigate the causes of crashes from the perspective of a human, environmental/road, and traffic factors. In the human factor class, factors such as age and gender of road users, as well as the usage of alcohol and drug in many studies have been reported as influential factors in causing crashes. Besides, the role of the geometrical conditions of the route, such as the standardization of the route design, as well as road lighting conditions belongs to the category of environmental/road factors. Furthermore, some factors such as the effect of traffic volume and vehicle speed are most factors in terms of the impact of the traffic situation on the possibility of crashes. In studies using questionnaire data, researchers generally intend to pay attention to subjects such as the behaviors and attitudes of road users, which could lead to risky actions under certain conditions by them. These behaviors are potential factors on increasing the possibility of risk of crashes and conflict between drivers and pedestrians through driving errors (misjudgments or failures of observation with potential for hazards or dangerous outcomes), lapse (minor attention or memory failures or absent-minded behaviors which may be frustrating or have negative consequences for the driver or pedestrian responsible, intentional and unintentional violations (violations of the law without any intention to do so). Field studies represent a practical understanding of the nature of questionnaire studies in real fields. In other words, these studies examine the behavioral patterns of drivers and pedestrians in the real fields of traffic flow from the perspective of supervisors. The purpose of the viewpoint is to determine the factors that could affect the decision of drivers and pedestrians. For example, pedestrian crossing styles such as running, walking, and pedestrian jaywalking model, as well as variables such as waiting time or pedestrian volume, could be a framework for assessing movement behavior and attitude patterns concerning the pedestrian gap acceptance model. Besides, assessing the role of vehicle speed on the likelihood of driver yielding model encountering pedestrians can more precisely examine drivers' actions. Table 3 shows some of the studies conducted through post-crash field observation.

### 2.2. *Results of the passive approach*

Some of the most important results obtained from different methods based on the passive approach are as follows.

- Drug use and alcohol by pedestrians as well as driver age were important factors in the probability of crashes. The 25–34 age group experience the highest rate of alcohol/drug involvement in crashes.
- Speeding and unauthorized overtaking are among the high-risk behaviors that may ultimately lead to a crash.
- Age is a significant variable on possibility of crashes. Of this, pedestrians over the age of 65 are the most vulnerable. The injuries and casualties can be attributed to their physical and visual disabilities.
- High-risk crossing behaviors of pedestrians such as running and zigzag crossing increase possibility of crashes.
- Inappropriate performance of driver including inability to control the vehicle, frequent lane changes, inattention to the traffic ahead before deciding on movements were the major contributors to crashes.
- The personal and social backgrounds of pedestrians have a high impact on their vulnerability risk in crashes. The results obtained have highlighted the importance of cultural factors in risk perceptions, and safety behaviors.
- Crossing unmarked areas was one of the main causes of pedestrian crashes.
- Hazard perception, understanding proper performance, and the traffic rules and regulations are three important factors that lead to behavior change in the driver in various ways and consequently in his/her decisions.
- Talking on the phone, texting as well as using headphones were identified as pedestrian distraction factors while crossing the street.
- Gender as a dominant variable effect the possibility of crashes. Women were less likely to intend to cross than men by risky crossing behavior. Males committed significantly more violations than females, and there is a negative correlation between age and frequency of violations.

### 2.3. *Limitations and disadvantages of the passive approach to pedestrian crossing safety analysis*

The process and usage of three different passive approaches to pedestrian crossing safety analysis were evaluated. Although these methods provide numerous benefits for researchers to better analyze pedestrian safety in certain conditions, numerous limitations have been mentioned by the researchers in the application of crash databases, survey data, and post-crash field observation data in safety analysis during the last decade. In general, these issues are related to the status of the data and the implementation of these methods.

- Data status

Non-availability of some crash data (Anastasopoulos and Mannering 2009; Caliendo et al., 2007; OECD, 2017) or lack of reports on property damage crash fatalities (Lord and Bonneson, 2007; Wood, 2002) makes comprehensive information about crashes in a community not available. This may lead to the failure to achieve a general pattern of crashes in these communities. Besides, intervals of 3–5 years are required to assess the causes of crashes in a particular area (Laureshyn et al., 2010; Lord and Bonneson, 2007), which may make it difficult to follow up on some related issues, such as possible changes in route geometry design (Lord and Mannering, 2010; Lord and Persaud, 2000). Also, considering agreed with the international definition of death within 30 d after a crash occurred, there are known difficulties in following up on the casualties for 30 d (Wilson, 2015).

- Implementing methods

In implementing methods, temporal and spatial issues may affect the data collected. For example, in assessing the causes of crashes based on a database study, there is no information about the behavioral conditions of road users before crashes (Laureshyn et al., 2010; OECD, 2017). Also, lack of accurate information in the questionnaire (self-reporting

**Table 3 – Studies based on post-crash field observation.**

| Reference | Study subject (country) | Variable | |
|---|---|---|---|
| | | Independent | Dependent |
| Torres et al. (2020) | Pedestrian behavior (Brazil) | Pedestrian characteristics and behavior | Driver yielding behavior |
| Gao et al. (2019) | Safety impact of right-turn waiting area at signalised junctions conditioned on driver's decision-making based on fuzzy cellular automata (Singapore) | Pedestrian characteristics and behavior | Driver yielding behavior |
| Poó et al. (2018) | Explore risky pedestrian crossing behaviors in traffic intersections (Argentina) | Different stages of the crossing process, traffic code violations, and other potentially risky behaviors such as distraction | Crossing risk index |
| Wang et al. (2018) | Identification and prediction of large pedestrian flow in urban areas (China) | Activities related to crossing streets and related to walking | Risky behavior |
| Zhang et al. (2017) | Effect of age on children's pedestrian behavior (China) | Smartphone | Pedestrian flow detection |
| Sucha et al. (2017) | Pedestrian-driver communication (Czech Republic) | Pedestrian density, waiting time, conflicts observed, crossing width, driver not yielding to pedestrian | Driver yielding behavior |
| Papadimitriou et al. (2016) | Towards an integrated approach of pedestrian behavior and exposure (Greece) | Road, traffic, and human factor | Pedestrian crossing risky behavior |
| Kadali and Vedagiri (2013) | Assessment of pedestrian-gap acceptance on lanes with and without lane (India) | Gender and age of pedestrian | Pedestrian decision |
| Zhuang and Wu (2013) | A study of the set of pedestrian dangerous behaviors in lanes without lines (China) | Pedestrian movement | Risky behavior |
| Mitman et al. (2010) | Comparing the behavior of drivers (USA) | Pedestrian age and gender, pedestrian willingness to cross faster, pedestrian speed | Driver and pedestrian decision |
| Cambon de Lavalette et al. (2009) | Pedestrian crossing decision-making (Canada) | Pedestrian behavior | Risky behavior |
| Rosenbloom et al. (2008) | Pedestrian tendency to cross on a red light (Israel) | Age, gender, religiosity, location | Risky behavior |
| Lassarre et al. (2007) | Measuring crash risk exposure for pedestrians (France) | Junctions and mid-block location | Pedestrian crossing behavior |
| Rosenbloom et al. (2004) | Effect of the elements of religiosity and faith on pedestrian behavior (Israel) | Running a red-light, crossing where there is no crosswalk, walking along the road | Risky behavior |
| Sisiopiku and Akin (2003) | Analyze user behaviors, perceptions toward various pedestrian facility (USA) | Effect of age and gender | Pedestrian decision |
| Hakkert et al. (2002) | An evaluation of crosswalk warning system (Israel) | Speed change | Driver yielding behavior |
| Hamed (2001) | Investigation of pedestrian behavior when crossing the road (Jordan) | Pedestrian group, traffic headway, gender, age, and the number of attempts to cross | Driver yielding behavior |

bias) (Brener et al., 2003; Demetriou et al., 2015; Kawulich, 2012) or some problems such as the high cost of using on-site supervisors for post-crash field observations (Kawulich, 2012) and inadequate or limited statistical population in the questionnaire/post-crash field observations (Brener et al., 2003; Claudio et al., 2020; Demetriou et al., 2015; Kawulich, 2012) may affect the quality of methods.

Considering the limitations of the passive approach, in recent years, extensive research has been undertaken by researchers to use an active approach to crashes and events in proximity to pedestrian crashes such as traffic conflicts. The importance and necessity of improving pedestrian traffic safety have required researchers to study closely the interactions between the factors involved in an event. As noted in the introduction, the causes of a crash can be categorized into the human, environmental/road, and vehicle factors, although the effect of the human factor in a crash is more than others.

## 3. Review of active approaches

Regarding pedestrian traffic safety, recognizing the behavioral differences of road users, including drivers, pedestrians and others involved in a crash could also affect pedestrian safety. Identifying the effective factors, understanding cause and effect patterns, and finally providing recommendations and applying safety measures to reduce or eliminate the crash factors are among the achievements of recent studies. In general, the studies aimed at the safety of pedestrian traffic can be divided into two general groups, regardless of the crash or proximate events (such as traffic conflict). The first group consists of studies using the simulation of pedestrian crashes or conflicts in driving simulators. The second group of active approaches to pedestrian traffic safety consists of on-road studies that involve videography. The term "conflict" in traffic studies was first used by Perkins and Harris (1967) to identify vehicle safety problems. The concept was based on observation of various events in which the driver avoids a crash. Such measures should be identified by some observable reactions, such as hard braking or sudden lane change (assuming critical conditions for the driver's performance). The definition of the actual scale for measuring the severity of conflict was first reported by Spicer (1973). Thereafter, Kraay (1987) conducted his study based on conditions in which two road users confronted each other and neither of them had an evasive maneuver. Accordingly, the point at which the evasive maneuver was performed through observation was recorded as the "time to the crash". This value was analyzed along with the speed to determine if the conflict is serious. In general, the definition of a traffic conflict technique implies a consistent hierarchical description of interactions and collisions. Researchers have proposed several models to introduce the concept of intensity. In their research, Glauz and Migletz (1980) proposed a distribution function based on proximity to a collision to determine the intensity scale. However, one of the most acceptable diagrams was introduced by Hyden (1987) as a pyramid. The crashes are at the top of the pyramid, followed by safe driving with few interactions at the bottom level. Almost all definitions of traffic conflict can be divided into two general categories: traffic conflict based on evasive performances; traffic conflict based on temporal (and (or) spatial proximity).

- Traffic conflict based on evasive performances

With this criterion, traffic conflict is defined through the evasive performances of road users. The definition of evasive-based traffic conflict is as follows: "an event involves two or more road users in which the performance of one user makes the other take an evasive maneuver to avoid collision" (Parker and Zegeer, 1989). According to this definition, conflicts related to such events can be detected by observing the brake light or unexpected lane change by the driver. Therefore, these evasive performances should be observed to detect traffic conflict. Several conflict studies have been conducted following a similar approach in some countries (Muhlrad, 1993; Sayed et al., 2013). According to this definition, conflicts and crashes are the same, except that successful evasive performance in the conflicts prevents crashes from occurring. Challenges related to observing conflicts based on the evasive performance were pointed out by various researchers such as Chin and Quek (1997), and Zheng et al. (2014). Evaluation of traffic conflict based on evasive performance may lead to a diversified path defining, identifying, and interpreting conflicts. Firstly, as the field observer is familiar with what to capture, a list of possible evasive performances should be identified. Without the use of advanced technology, this approach has been challenged on many accounts. Besides, it was proved that not all of the driver's observable performances are inherently necessary. For example, drivers may use braking as a precautionary measure to reduce potential risk, rather than as an evasive technique to avoid collision. The distinction between a precautionary and an evasive performance should be taken into account. There may be problems with evasive performances with conflict when the conflict is used as an alternative to an crash. It is argued that crashes occur after conflicts, i.e. conflict must occur before an crash based on evasive performances. However, this argument has often been challenged, with some crashes occurring when drivers did not show any reaction. In addition, evasive performances may sometimes be absent in many critical situations. Some evasive performances may be merely precautionary such as braking or lane-changing that does not indicate a hazardous situation (Chin and Quek, 1997). Therefore, if conflict is purely based on evasive performances, a proper relationship may not be defined between crashes and conflicts. However, usually the traffic conflict techniques are used to verify the predicted validity of such relation.

- Traffic conflict based on temporal (and (or)) spatial proximity

Vehicles closer to each other, whether on a spatial or temporal scale, may collide sooner than other vehicles. The definition of traffic conflict based on proximity was given by Hyden: "traffic conflict is a situation where there are one or more vehicles, based on which there is a certain risk of collision between them if the displacement of one of the two users (or both) remains unchanged" (Hyden, 1987). One of the most important benefits of this definition is that all collisions occur before the conflict. Also, this method is purposeful and objective because the interactions can be measured quantitatively. Quantitative measurement is relatively objective and presents an interpretable situation in terms of proximity to the collision. Besides, the definition of spatial or temporal proximity is easily understood. Several types of proximity indices have been proposed to evaluate safety in traffic, operational, and geometric conditions (Zheng et al., 2014). These indicators can be broadly divided into two groups: temporal and non-temporal. Non-temporal measures can also be categorized by distance and deceleration among other variables. In the process of design and implementation of the algorithm, data from the captured videos can be extracted after performing naturalistic driving studies. In the next step, the vehicle-pedestrian interactions are identified and their values are determined by various indicators related to alternative safety measures such as the Swedish traffic conflict method, based on variables such as vehicle speed and distance between vehicle and pedestrian. In fact, after each conflict, by computing different variables based on multiple indicators of alternative safety measures at the time of drive's evasive performance, all conflicts are considered for the clustering operation in the next step.

### 3.1. *Methods*

#### 3.1.1. *Safety analysis through a driving simulator*

The use of driving simulators for research began in the 50s and has peaked in the 21 century. Nowadays, it is one of the most popular subjects in transportation engineering. To reduce costs and increase safety, the use of driving simulators has increased in driver behavior studies. Although the initial cost of driving simulators is relatively high, they are very cost-effective due to their low operation cost. Also, since studies are carried out in the lab in all study phases, it provides sufficient safety for users, especially in traffic crash tests, where there is no harm to the users. Also, it allows researchers to make controlled experiments. Transport engineers have therefore moved from the real world to the virtual world and to driving simulators to conduct behavioral studies of drivers. The use of these driving simulators is on the rise and improvements have been remarkable. Many large automakers around the world have already established highly advanced facilities in this field. Numerous studies have been conducted on pedestrian safety in the driving simulator environment, which is outlined in Table 4.

In general, driving simulator studies examines the attitudes and behaviors of road users regarding the traffic situation in which they are involved. Evaluating these topics could provide researchers a more explicit understanding of road users' decision-making in certain conditions. The possibility of encountering dangerous driving conditions without being physically at risk through these studies has led researchers to efficiently assess traffic issues such as the distraction behavior of road users as well as their hazard perception toward road traffic. Different scenarios by designing roads with particular traffic and geometric characteristics allow researchers to study the reactions of road users. These reactions determine the risk of these scenarios through various models, such as the pedestrian gap acceptance model or the driver yielding behavior model. Moreover, in these studies, the possibility of examining the interactions could lead to the determination of road users' reaction models when encountered with each other.

#### 3.1.2. *Pedestrian safety studies through fixed videography*

Evaluating pedestrian and driver behaviors by installing a camera in a crash-prone site or where there may be a potential collision between a vehicle and pedestrian is one of the most common pedestrian traffic safety approaches. According to the previous section, disadvantages, and limitations of the passive approach, the researchers sought to provide an approach to achieve a collection of behaviors and performances of the road users. Although the use of driving simulators may compensate for some limitations of passive approaches, in this approach too, some problems prevent precise evaluation of the road user behaviors in near-crash locations. Therefore, nowadays, the use of videography is very common among researchers to make up for the limitations of previous approaches. The most basic and most popular type of videography in contemporary research is the use of stationary cameras on the study routes. In such studies, by mounting the cameras at the highest point overlooking the route, safety studies are performed by recording the natural behaviors of road users such as drivers, pedestrians, and so on. Some of the studies that have used this approach are reviewed below. Then, the limitations of this method are discussed. This kind of analytical approach makes it possible to examine the traffic flow in greater detail. In other words, the use of cameras or videography of the traffic flow results in a more detailed evaluation and also allows frequent observation of the behavioral characteristics of road users before, during, and after any crash (Jonasson and Rootzén, 2014; Sullivan et al., 2015). By observing the recorded videos, the researchers extract the required data and analyze the traffic safety risk of the study routes using a variety of methods. It should be noted that it is possible to collect traffic microdata including successful attempts, flow direction, and kinematics information of road users at different moments through videography analysis. Numerous studies have been carried out by researchers through mounting fixed cameras in various directions, some of which are mentioned in Table 5. Collecting data by installing a camera in the path allows researchers to high detailed monitor the pedestrian crossing behaviors than observational studies (by on-site supervisors). In these studies, examining the pedestrian behaviors is feasible before crossing as well as during crossing. Besides, the analysis speed of the vehicle approaching pedestrians, as well as the distance between the vehicle and the pedestrian at different time intervals is feasible if the camera could cover the area. In these studies, the evaluation of pedestrian decision-making behavior through gap acceptance models as well as the vehicle-pedestrian interaction models are the most important topics of interest to researchers.

#### 3.1.3. *Safety analysis through videography in motion (naturalistic driving study)*

Naturalistic driving studies were performed to examine the behavior and performance of drivers and other road users as they interact with each other. The first formal application of this method may be attributed to a safety project sponsored by the National Highway Traffic Safety Administration (NHTSA) in 2006. This was a new approach to the current traffic investigation methods and provides information that is difficult or even impossible to achieve by other methods (Van Schagen et al., 2012). In this approach, user behavior is continuously investigated in a natural environment for a long time. The European Transport Safety Council's final report defines the naturalistic driving studies as: “research studies to find out more about driver behavior on daily trips through recording details of the driver, vehicle and environmental performance by using types of equipment and without control devices”. According to this definition,

**Table 4 – Studies based on driving simulator.**

| Reference | Study subject (country) | Variable | |
|---|---|---|---|
| | | Independent | Dependent |
| Dozza et al. (2020) | Pedestrian-vehicle near-miss (Sweden) | Crossing side, car speed, pedestrian speed, crossing angle, pedestrian size, zebra-crossing presence | Driver's response process |
| Zhang et al. (2020) | Pedestrian-vehicle near-miss (USA) | Post encroachment time to collision | Possibility of collision |
| Kutela and Teng (2019) | Pedestrian-vehicle near-miss (USA) | Number of lanes, high incoming vehicle speed | Possibility of collision |
| Large et al. (2019) | Pedestrian-vehicle near-miss (UK) | Time to collision | Urgency and modality of pedestrian |
| Mizoguchi et al. (2017) | Pedestrian-vehicle near-miss (Japan) | Time to collision | Possibility of collision |
| Obeid et al. (2017) | Pedestrian-vehicle near-miss (Lebanon) | Time to collision<br>Time to zebra crosswalk | Possibility of collision |
| Yoshizawa and Iwasaki (2017) | Pedestrian-vehicle near-miss (Japan) | Gazing behavior of the driver | Possibility of collision |
| Takanashi et al. (2015) | Pedestrian-vehicle near-miss (Japan) | Time to collision time to vehicle | Possibility of collision |
| Matsui et al. (2013) | Pedestrian-vehicle near-miss (Japan) | Time to collision time to vehicle | Possibility of collision |
| Mollu et al. (2018) | The influence of digital illuminated billboards near pedestrian crossings (Belgium) | Driver behavior | Driver distraction |
| Feldstein et al. (2016) | Evaluate critical road crossing (Germany) | Pedestrian crossing behavior | Pedestrian crossing decision making |
| Chrysler et al. (2015) | Pedestrian crash scenarios in a driving simulator environment (USA) | Pedestrian crash trajectories, speeds, roadside features, and pedestrian behavior | Develop crash pattern |
| Dommes et al. (2014) | Comparison of young and old pedestrian crossing (France) | Pedestrian behavior | Pedestrian crossing decision making |
| Dommes et al. (2013) | The effects of functional decline in older pedestrian safety (France) | Pedestrian walking speed | Pedestrian crossing decision making |
| Gómez et al. (2013) | Evaluating the effect of sign and direction marking on drivers' performance (USA) | Traffic sign | Driver yielding behavior |
| Charron et al. (2012) | Child pedestrians behavior crossing the road (France) | Pedestrian behavior | Pedestrians' risky crossing behavior |
| Stavrinos et al. (2011) | The effect of cell phones on pedestrian safety (USA) | Demographics and attention of pedestrian | Pedestrian distraction |
| Holland and Hill (2010) | Gender differences in factors predicting unsafe crossing decision (United Kingdom) | Gender, age | Pedestrians' unsafe crossing decision |
| Hatfield and Chamberlain (2008) | The impact of in-car displays on drivers (Australia) | Driver behavior | Driver distraction |
| Oxley et al. (2005) | Age differences in gap selection by pedestrian (Australia) | Pedestrian age | Pedestrian gap acceptance |

this approach provides researchers with the opportunity to identify and analyze the relationship between the driver, vehicle, road, and other road users during different driving situations (Van Schagen et al., 2012). In other words, the "naturalistic driving study" refers to a flexible approach to the study of driver behavior. This approach helps researchers to better study driver's behavior by monitoring driving duties and the road environment and gives recommendations on the measures that the driver should take before or near a crash.

All-natural data are collected in the course of actual traffic. Video is an important part of the researches using a naturalistic approach. Videos are used to understand driving behavior as well as the interaction between drivers and their environment. Most of these studies include at least one front-facing camera and another one focusing on the driver's face and/or body to identify his/her actions and reactions. However, in some studies, the only video captured was related to the route in the front. Additional cameras may include the ones for: 1) a close-up image of the driver's face to observe the eye movements and facial expressions, 2) image of the driver's feet to observe the driver's braking and reaction times, 3) a rear camera to study the effect of vehicles behind on driver behaviour, 4) side images to observe the actions of other road users in complex environments such as intersections on driver behavior (Habibovic et al., 2013; Sheykhfard and Haghighi, 2020b; Sun and Elefteriadou, 2012). Additional sensors in the vehicle are usually used to provide specific information on key features of the interaction between the driver, the vehicle, and the environment, for example, 1) radar to observe conditions of other road users, 2) accelerometer and speedometer for studying the brakes, acceleration, and driving behavior, 3) GPS for vehicle positioning, and 4) traffic sign reading. Other tools may be considered in naturalistic studies, such as the eye-tracking system, although some studies indicated poor efficiency of eye trackers in the detection of the eye movements of the driver. Table 6 lists some of the studies using this approach.

Overall, NDS provides a significant opportunity to examine the interactions of road users when interacting with each other. Data collection by this method could lead to evaluate users' behaviors in high detail than the fixed videography method in various temporal and proximity intervals. Besides, determining the major factors affecting the decision-making behavior of road users is achievable. Due to the significant role of driving errors in the occurrence of crashes, NDS allows researchers to be able to inspect the communication between road users from the driver's perspective. On the other hand, a comprehensive assessment of the interactions between drivers and pedestrians in these studies led to provide more comprehensive models of driver yielding behavior and vehicle-pedestrian conflict than in the past. Overall, NDS provides a significant opportunity to examine the interactions of road users when interacting with each other. Data collection by this method could lead to evaluate users' behaviors in high detail than the fixed videography method in various temporal and proximity intervals. Besides, determining the major factors affecting the decision-making behavior of road users is achievable. Due to the significant role of driving errors in the occurrence of crashes, NDS allows researchers to be able to inspect the communication between road users from the driver's perspective. On the other hand, a comprehensive assessment of the interactions between drivers and pedestrians in these studies led to provide more comprehensive models of driver yielding behavior and vehicle-pedestrian conflict than in the past.

### 3.2. *Results of the active approach*

The following are some of the most important findings that researchers have reported through active studies.

- The preventive warning systems are useful for avoiding traffic crashes.
- Older pedestrians fall in more dangerous decisions that led to collisions with approaching cars.
- Men differed from women in making unsafe crossing decisions.
- The rolling gap crossing mode is the most dangerous way to cross the uncontrolled mid-block crosswalks.
- Speed of approaching vehicle, number of unsuccessful attempts of pedestrian before crossing as well as the pedestrian zigzag movement are among the most important factors that can lead to choosing a safe/hazardous gap for pedestrians.
- Increasing the level of conflict severity causes drivers to yield a harsh-maneuver such as emergency braking to prevent collision.
- Digital billboards can lead to driver distraction and thus increase the potential for car-to-car and car-pedestrian collision.
- Pedestrians usually exhibit safer behaviors over long distances of walking. Also, variables of age and gender were among the factors that led to differences in pedestrian behaviors when crossing the street.
- The results show that pedestrians have accurate estimation intervals that vary by weather conditions.
- Pedestrians show aggressive behaviors such as running on the road in small gap which reduce crossing safety.
- Driver yield rates were found to be lower to jaywalkers than to permissible crossings by pedestrians.

### 3.3. *Limitations and disadvantages of the passive approach to pedestrian crossing safety analysis*

#### 3.3.1. *Driving simulators*

Below are mentioned some limitation of using driver simulator (Brooks et al., 2010; Winter and Happee, 2012).

- Authenticity and validity

The most important problem with simulator research is that the real world cannot be fully simulated in every detail. So, despite the great effort of graphic artists, there are still many differences between the simulated and the real situations. Also, drivers do not employ as much care in the simulator as they would in the real world. One of the problems with the validity of simulator devices is the correspondence of the driver's behavior in the simulated and the real world. So, given the researches comparing driver behavior in the simulated and the real world, the validity of the device can be estimated and used as a good approximation for studies that are performed only using the simulator.

- Initial cost

Driving simulators have a high initial cost. The costs of setting up, running, and maintenance of the research simulators are slightly higher than training simulators, as research simulators are more complex. Of course, these fixed costs will not be repeated for the years to come, and only maintenance cost is incurred.

**Table 5 – Studies based on fixed videography.**

| Reference | Study subject (country) | Variable | |
|---|---|---|---|
| | | Independent | Dependent |
| Kathuria and Vedagiri (2020) | Evaluating pedestrian-vehicle interaction (India) | Time to the collision, gap time, post encroachment time | Conflict model |
| Layegh et al. (2020) | Modeling the pedestrian-pedestrian conflict (Iran) | Time-to-collision (TTC) and post-encroachment time (PET) | Conflict model |
| Guo et al. (2020) | Analysis of conflict-based before-after safety evaluation of leading pedestrian intervals (China) | Traffic conflicts of different sites and period | Conflict model |
| Zhang et al. (2019) | Evaluation of pedestrian crossing behaviour (China) | Pedestrian characteristic | Pedestrian crossing behavior |
| Wu et al. (2018) | Improving safety in dilemma zone at signalized intersections based on cellular automata simulations (USA) | Driver behavior | Stop/go decision |
| Xu et al. (2018) | Analysis of pedestrian crossings on suburban roads (China) | Type of pedestrian crossing, speed of vehicle | Pedestrians' perception |
| Qi and Guo (2017) | Influence of left-turn movement on pedestrian safety (China) | Number of lanes per intersection, speed of cars, percentage of heavy vehicles on the lane | Conflict model |
| Minhas et al. (2017) | Investigating the interactions of road users at urban intersections when pedestrian gap acceptance (Pakistan) | The behavior of drivers based on their age, gender, and type of traffic control present at the intersection | Pedestrian crossing behavior |
| Lu et al. (2016) | A cellular automaton simulation model for pedestrian and vehicle interaction behaviors at unsignalized mid-block crosswalks (China) | Pedestrian and driver behavior | Pedestrian crossing behavior |
| Ni et al. (2016) | Assess pedestrian safety at intersections (China) | Driver action | Interaction model |
| Hunter et al. (2015) | Modeling the behavior of drivers based on giving/not giving priority to pedestrians (USA) | Driver action | Interaction model |
| Li and Han (2015) | Behavioral effect on pedestrian evacuation simulation using cellular automata (China) | Driver action | Interaction model |
| Hiyoshi et al. (2014) | Pedestrian movement model based on voronoi cellular automata (Japan) | Driver action | Interaction model |
| Serag (2014) | Modeling safe pedestrian crossing behaviour (Egypt) | Traffic flow conditions, road users' performance were captured by filming in a tall building overlooking the motorway | Pedestrian gap acceptance |
| Salamati et al. (2013) | Investigation of pedestrian crossings in the areas near the overcrowded squares of the study sites (USA) | All motor behaviour of cars and pedestrian | Driver yielding behavior |
| Li et al. (2012) | Using cellular automata to investigate pedestrian conflicts with vehicles in crosswalk at signalized intersection (China) | Pedestrian and driver behavior | Conflict model |
| Alhajyaseen et al. (2012) | Assessment of pedestrian safety (Japan) | Gap, vehicle speed, vehicle size | Conflict model |
| Johansson et al. (2011) | Assessment of pedestrian safety (Sweden) | Vehicle speed, gender, age, number of people in the group, pedestrian speed | pedestrian crossing behavior |
| Strong and Ye (2010) | Effects of yield-to-pedestrian channelizing devices (USA) | Motorist and pedestrian behavior | Driver yielding behavior |
| Brewer et al. (2006) | Pedestrian gap-acceptance behavior (USA) | Rejected gap, accepted gap, and driver behavior | Pedestrian gap acceptance |
| Sun and Ukkusuri (2003) | Motorist-pedestrian interaction (USA) | Age, gender, waiting time, head size, and size of the crossing group | Pedestrian gap acceptance |

**Table 6 – Studies based on naturalistic driving study.**

| Reference | Study subject (country) | Variables | |
|---|---|---|---|
| | | Independent | Dependent |
| Sheykhfard et al. (2021a, b) | Vehicle-pedestrian conflicts in marked and unmarked crosswalks (Iran) | Time to crash (TA)<br>Conflicting speed (CS) | Severity of the conflict |
| Sheykhfard and Haghighi (2020a) | Driver distraction (Iran) | Drivers behavior | Driver distraction |
| Sheykhfard and Haghighi (2020b) | Vehicle-pedestrian interaction (Iran) | Vehicle speed, the distance of the vehicle to a pedestrian at the possible collision point | Pedestrian gap acceptable behavior |
| Van Nes et al. (2019) | Understanding of driver behaviour (Netherlands) | Driver age and gender | Driver decision making |
| Lin et al. (2018) | Investigating driver compliance with pedestrian features at signalized intersections (USA) | Type of driver compliance with selected pedestrian feature at signalized intersections | Driver decision making |
| Wu and Xu (2017) | Driver behavior analysis for right-turn drivers at signalized intersections (USA) | Different factors of driver, vehicle, road, and environment | Driver decision making |
| Antić et al. (2016) | Pedestrian movement (Serbia) | Age and gender of pedestrian | Pedestrian crossing behavior |
| Sun et al. (2015) | Pedestrians crossing safety (China) | Vehicle speed and stopping distance to the pedestrian | Pedestrian crossing behavior |
| Tian et al. (2015) | Vehicle-pedestrian potential crash (USA) | Drivers and pedestrians' behavior | The risk level of the encounter |
| Habibovic et al. (2013) | The pattern of events between drivers and pedestrians (Japan) | Number of lanes per intersection, speed of cars, percentage of heavy vehicles on the lane | Interaction model |
| Uchida et al. (2010) | Investigation of factors contributing to major crash types (Japan) | Drivers and pedestrians' behavior | Conflict model |
| Ackermann et al. (2019) | Pedestrians and automated vehicles interaction (Germany) | Drivers behavior | Driver yielding behavior |
| Sheykhfard and Haghighi (2019) | Investigation of the performance of car drivers when dealing with pedestrians (Iran) | Drivers' actions to prevent pedestrian collision | Driver yielding behavior |
| Shinmura et al. (2018) | Driver's insight for safe passing based on pedestrian attributes (Japan) | The acceleration rate of vehicle | Pedestrian crossing |
| Palmeiro et al. (2018) | Interaction between pedestrians and automated vehicles (Netherlands) | Pedestrians' behavior | Pedestrian gap acceptance |
| Jurecki and Stańczyk (2018) | Analyzing driver response times for pedestrian intrusions (Poland) | Time to collision | Driver braking behavior |
| Sheykhfard and Haghighi (2018) | Causes of conflicts between cars and pedestrians (Iran) | Drivers and pedestrians' behavior | Conflict model |
| Cafiso et al. (2017) | Conflicts between vehicle-pedestrian (Italy) | The traffic conflict technique | Conflict model |
| Zheng et al. (2017) | Driver yielding to the pedestrian presence on unmarked and marked crosswalks (USA) | Age, gender, driving experiences of driver | Pedestrian crossing |
| Zheng et al. (2015) | Modeling vehicle-pedestrian interactions outside of crosswalks (USA) | Pedestrian and jaywalkers' reactions to driver yield | Vehicle yield/no-yield decision |
| Jurecki and Stańczyk (2014) | Driver reaction time to lateral entering pedestrian (Poland) | Time to collision | A reaction time of drivers |
| Schmidt and Färber (2009) | Effect of vehicle speed and TTC on pedestrians' intentions to cross (Germany) | Pedestrian detection and distance | Time to collision |

- Sickness in simulators

Sickness in simulators is because the subject sees some interactions in the image before himself, but in practice, nothing happens and this conflict results in psychological stress on the user. For example, when the driver presses the brake pedal he expects negative acceleration from the vehicle, but in practice, this does not happen in fixed bed/static simulators. If the bed of the simulator is movable, a lot of acceleration and force are expected from the vehicle during the crashes, which is not the case in reality. Also, even with dynamic simulators, due to the processing delays in the system, the time of viewing is slightly different from the time of shaking and negative psychological stress is exerted. Sickness may vary widely between subjects or between simulators. The effects may range from mild dizziness to severe muscle disability and complete nausea.

#### 3.3.2. *Fixed-camera videography*

Despite the significant benefits of using fixed cameras, there have been some limitations and difficulties in evaluating some of the road users' behavioral parameters. These challenges eventually led to the inefficiency or incompatibility of fixed-camera videography in some study scenarios. The disadvantages and limitations of such studies were (Fitch and Hanowski, 2012; Knoefel et al., 2018; Sheykhfard and Haghighi, 2019; Van Schagen and Sagberg, 2012).

- Failure to investigate behavior variations of road users at different road sections before and after the study area
- Impossibility of evaluation of events from the driver's perspective
- Lack of access to driver behaviors and performances

Accordingly, videography in motion (installing cameras inside the vehicle) was introduced in traffic safety studies to address the aforementioned limitations.

#### 3.3.3. *NDS*

Despite the many advantages of NDS over other methods, it also has some potential limitations that must be considered in studies.

- Users may try to behave better than they normally would appear more socially desirable or acceptable when they know they are being observed (for example, the effect of the inside camera on the driver's behavior). Therefore, the effect of data collection devices may affect their natural behavior.
- In this method only users' behaviors could be observed and analyzed, so the researcher may not be able to identify the cause of a specific behavior. For example, the cause of a frequent red light violation by the driver may be unknown to the researcher, which is due to work stress or mental health problems.
- Researchers may have different views and perceptions of user behavior. For example, observing videos recorded during an NDS may lead to differential data mining from observers.
- Depending on the different tools and devices used in these studies, NDS can be very costly, and the implementation of the framework would be complicated.

## 4. Summary and discussion

In the present paper, the set of studies was categorized into two general approaches: passive and active. Although the passive approach is known as a valuable tool for determining the main causes of crashes, due to some of the limitations mentioned, it is not very reliable. Accordingly, the active approach has been used in recent years as a new perspective in the field of pedestrian safety studies. The utilization of an active approach has been evaluated to predict vehicle-pedestrian near-miss events such as traffic conflicts and to assess pedestrian crossing safety. On the other hand, given the importance of pedestrian traffic safety, the analysis of the structure of vehicle-pedestrian conflict by taking an active approach can lead to improving pedestrian traffic safety by improving the behavioral performance of vehicle drivers and pedestrians.

On the other hand, examining traffic conditions, especially the behavioral characteristics of road users, is a significant way to better understand the complicated conditions that arise between vehicle drivers and pedestrians. In general, the risk of crashes can be considered as a function of the probability of the event and the severity of the consequences. In other words, the conditions in which drivers and pedestrians encounter each other, if they are likely to collide with each other, in a way indicate the causal pattern of the risk of crashes between them. Determining causal patterns of crash risk is a valuable step in advancing the identification of events with a high risk of pedestrian crashes. The occurrence of high-risk traffic conflict can be the cause of the risk of collision. Regarding pedestrian crashes, considering the role of driver and pedestrian as two important human factors involved in the interaction, their behavior and attitude should be evaluated at different times facing each other. To be clearer, identifying the casual pattern of road users' behavior shows vital information to assess different aspects of a vehicle-pedestrian conflict. Finally, this approach can be used to express the risk of pedestrian crashes as the output of the process of the traffic studies. So far, several studies have been conducted on the causes of pedestrian collisions, which indicate the main role of the human factor compared to other factors in the occurrence of the possibility of pedestrian crashes. Despite the findings of these studies as well as their implementation strategies, global reports indicate that the number of pedestrian crashes is still significant (WHO, 2018). In these reports, the role of human error related to the driver factor is significant, which highlights the need to improve driver performance. Therefore, due to the role of drivers' defects in crashes, the need for a driver-assisting factor that can lead to improved driver performance is felt. This factor, to improve the driving duties of drivers, can play a major role in improving pedestrian crossing safety and, consequently, reduce the risk of crashes. Despite the development of advanced driving assistance systems (ADAS) in the field of safety systems of vehicles, there has been limited research on ADAS systems in the field of pedestrian crossing safety. Although the development of technology in the development of new tools plays an important role in establishing a framework for ADAS systems in pedestrian research, more extensive research on pedestrian safety in ADAS systems needs to be increasingly focused. Using advanced tools and technology, this research can make a significant contribution to the development of new ideas and provide a kind of basic framework for pedestrian safety systems through ADAS systems in the coming years. With the advancement of technology in the coming years, these ideas can lead to the establishment of the application of these systems in the automotive industry.

## 5. Conclusions and further research

Pedestrian safety studies have been one of the most important issues of traffic safety in the past decades. Numerous studies have used different approaches and methods to identify the safest solution for pedestrian safety by considering the problems in different environments. Although many of these studies have led to urgent solutions to address the issue of researchers in their study environments, official statistics continue to indicate that pedestrian fatality rates are still high. The present paper attempted to manifest the findings and limitations of pedestrian safety studies by examining the different approaches to vehicle-pedestrian conflicts and crashes studies. So, 160 studies were categorized into two different approaches, active and passive. In the passive approach, the three most important methods used by researchers to collect data are: 1) crash database, 2) questionnaire data, and 3) post-crash field observations.

Examining studies through these methods would lead to identifying the causes of crashes, recognizing the attitude of road users to the issue of safety, and determining road users' behavioral patterns in certain situations. Variables such as a person's characteristics (such as age, gender, and physical ability), road characteristics (such as standard design and lighting status) were among the most important causes reported by researchers in studies through a crash database. Also, a group of errors, lapses, intentional and unintentional violations by drivers or/and pedestrians which can lead to vehicle-pedestrian conflicts and crashes were presented by studies through questionnaire data. Besides, observation studies by supervisors also reported a set of factors that influence drivers 'and pedestrians' decisions encountering each other such as driver and pedestrian distractions, vehicle speed, and distance between vehicle and pedestrian.

On the other hand, the active approach could compensate for some of the limitations of the passive approach. Although some limitations have been reported for the active approach, however, this approach has led to a more detailed understanding of the behaviors and attitudes of road users.

Driving simulator systems are among the most common methods in the active approach that could provide researchers a more specific perception of road users' decision-making in certain conditions. Also, videography is another method that enables researchers to monitor in detail road users' behaviors than the passive approach such as observational studies.

NDS is one of the latest methods used in the active approach compared to other methods, which support researchers to consider the safety problems of pedestrians from the perspective of drivers. This method could exhibit a clearer understanding of the communication between vehicles and pedestrians by monitoring the behavior of the drivers at different time intervals before reaching the pedestrian crossing point, as well as observing the crossing behavior of the pedestrians when encountering the vehicle.

Generally, some of the critical findings of this paper based on the studies reviewed are given below.

- Risky behaviors are the most important factor in threatening pedestrian safety. These behaviors are a set of behaviors that put the pedestrian at risk of death or injury due to violating the legal rule by them or drivers of a vehicle approaching. The unauthorized speeding, non-compliance with traffic law, unauthorized overtaking by drivers, and illegal crossing, as well as aggressive crossing behavior such as running by pedestrians, are identified as the most important risky behaviors.
- Age is an influential factor in pedestrian safety among drivers and pedestrians involved in vehicle-pedestrian conflicts and crashes. Younger pedestrians are more likely to commit a violation in the same situation than older ones, although their physical condition and such as better mobility lead them less to be involved in conflicts and crashes. On the other hand, some features such as visibility, reaction time, as well as better ability to control the vehicle by young drivers have led this group to show a more dangerous driving than the elderly. Older drivers seek to overcome the problems of aging through positive/compensatory behaviors such as driving at a lower speed and maintains longer headway to other vehicles.
- The attitude of drivers and pedestrians significantly reflects their behavior in real conditions. Risk perception and decision-making processes are the most important bond between the attitude and behavior of road users in dangerous driving situations. These factors have caused people with relatively similar characteristics, such as age, gender, education, physical condition, and other cases, to be disproportionally involved in vehicle-pedestrian conflicts and crashes.

In general, past studies based on the NDS method focused individually on the communication between the approaching vehicles the pedestrians. This viewpoint overlooks the possible impact of the behavior of other road users such as cyclists and other vehicles on the behavior of pedestrians and drivers involved in a vehicle-pedestrian conflict and crash. Considering that each of these users is part of a system, analyzing the communications between each of these components could lead to a more comprehensive understanding of the problem of pedestrian safety. As NDS has made it easier for researchers to monitor vehicle-pedestrian conflict and crash than other methods, it seems essential to develop this method in future studies. In other words, creating a framework that enables researchers to monitor simultaneously the behavior of the whole group of road users involved in a certain area with aiming high detailed understanding of an event.

Although studies show that there is currently a set of research on the use of intelligent systems in pedestrian safety, more extensive research on pedestrian safety in ADAS systems needs to be considered. Given the key role of drivers in the occurrence of pedestrian crashes, it is suggested that future research focus on designing an intelligent algorithm that would assist the driver in critical situations when facing pedestrians. Therefore, the use of NDS to evaluate the interaction between drivers and pedestrians can lead to the establishment of a basic framework for the algorithm. The algorithm can improve pedestrian crossing safety by performing appropriate actions to prevent collisions with pedestrians in various situations in ADAS. It is important to note that despite the existence of numerous systems that can assist the driver in different situations, there is a lack of a system that can assist the action of drivers in the face of pedestrians.

## Conflict of interest

The authors do not have any conflict of interest with other entities or researchers.


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