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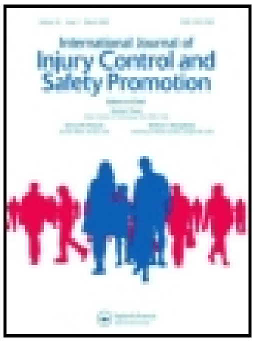

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Structural equation modelling of potential risk factors for pedestrian accidents in rural and urban roads

Abbas Sheykhfard[a,b], Farshidreza Haghighi[a], Trond Nordfjærn[c] and Mostafa Soltaninejad[d]

[a]Department of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran; [b]Faculty of Technology, Policy, and Management, Delft University of Technology, Delft, the Netherlands; [c]Department of Psychology, Norwegian University of Science and Technology (NTNU), Trondheim, Norway; [d]Jacobs Engineering Group, Omaha, NE, USA

ABSTRACT

Although several previous studies have focused on pedestrian safety, most of the studies have focused on urban roads. This study investigated accident data among 1358 pedestrians from 2012 to 2018 on urban, suburban, and rural roads in 16 cities in the Gilan province of Iran using structural equation modelling (SEM). Factor analysis showed that four exogenous latent variables had a significant relationship with fatal accidents among pedestrians. Factors related to roads (coefficient: 0.968), vehicles (coefficient: 0.632), humans (coefficient: 0.306), and the environment (coefficient: 0.194) were respectively the most important for pedestrian safety status. The main findings also proclaim that the poor quality of cars manufactured in Iran in addition to the poor design of intersections and major roads (urban) and ring roads (suburban) may be important reasons of the increased fatal accidents in the studied areas. A potential cause for these accidents may be rooted in less attention towards giving behavioural instructions to road users, and underdeveloped driver education procedures. Finally, the data-model fit of the SEM was validated using different indicators, and suggestions to improve safety were pointed out.

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Pedestrian; accident; safety; causal factor; road user behaviour

1. Introduction

It is essential to identify precursors of accidents and to provide a solution to eliminate or reduce the effect of these factors on the roads. This is particularly important for 'vulnerable' road users, such as pedestrians, who are more likely to experience injuries and fatalities in road accidents (WHO, 2018). Traffic investigators and engineers should first identify problems before taking any action on traffic issues and crashes and then take the necessary steps to reduce the influencing factors. By the increased urbanism during the past 50 years in the face of the positive economic and welfare effects of passenger and freight traffic, road accidents are still highly prevalent and increasing in some countries. According to the WHO (2018), road traffic deaths have reached 1.35 million annually, about 22 percent of which include pedestrians (WHO, 2018). According to the last report of the Iranian Legal Medicine Organization, the number of people killed in road accidents in Iran is 17183 cases including 4537 on urban roads and 11290 on suburban roads, and 1356 on rural roads, which represents an increase of 1.2% compared to 2017 (Iranian Legal Medicine Organization, 2018). Also, the Gilan province (population: 2530696 and area of 14,042 km^2), located in the northern part of Iran, is one of the provinces with the highest traffic accident rates. In comparison with road accident statistics in 2017 (fatalities: 628; injuries: 12,475), the number of fatalities and injuries has increased in 2018 (fatalities: 662; injuries: 12,827). The number of pedestrian fatalities caused by vehicle crashes in 2017 was 202 and 208 in 2018. The pedestrian to total mortality ratio in traffic accidents is 1:3, which is a large ratio. Therefore, it is necessary to investigate pedestrian accidents in an Iranian context, to identify potential precursors of accidents that can be targeted in safety interventions aimed to increase pedestrian safety.

According to the latest report by the World Health Organization (WHO) on the road safety, pedestrians are the most vulnerable group of road users who account for a significant share of road accidents (WHO, 2018). According to this report, an average of about 23% of the world's annual 1.35 million road fatalities involves pedestrians. An important aspect of pedestrian accidents is that many of the pedestrian accidents occur in particular areas (OECD, 2017; WHO, 2018) and there seems to be a geographic redistribution of the accident rates. Star roads are one of the most important of these areas (WHO, 2018). A sample of International Road Assessment Programme (iRAP) assessments from 54 countries, covering 358,000 km of rural and urban roads with over 700 billion vehicle kilometers of travel a year, has highlighted that 88% of pedestrian travels is on one or two-star roads (WHO, 2018). According to this classification, one or two-star roads refer to roads without any sidewalk or safe crossing point while the minimum speed of vehicles is 60 km per hour. The importance of this issue is that the excessive growth of the global population as

CONTACT Farshidreza Haghighi Haghighi@nit.ac.ir

well as geographical/environmental characteristics have led to a saturation of population density in some cities. In these cities, people are obliged to live in areas far from the city centres such as outskirt areas. Living in these areas and daily commuting to different urban areas are common around the world including in the northern part of Iran. What is important in this regard is the low level of safety on the roads that connect these areas to urban areas. To put it simply, considering that generally no safety measures are taken for the commuting of pedestrians on these roads, such roads are among the one-star roads, which, as reported by the WHO, are the most important pedestrian accident sites around the world (WHO, 2018). According to the Iranian Legal Medicine Organization report, pedestrian accident rate in the suburban and rural roads are more than 2.5 times that of urban ones. A significant share of these fatalities is on the suburban and rural areas (Iranian Legal Medicine Organization, 2018). From among 3505 pedestrians killed in the accidents in 2018, more than 66% have been killed on suburban roads, with 74% of them being killed on outskirt roads connecting to urban areas (Iranian Legal Medicine Organization, 2018). So, the present study aims to identify precursors of pedestrian accidents on all types of roads (urban, suburban, rural) of the Gilan province in Iran in terms of location and time, type of vehicle, geographical condition, gender, and age of pedestrians known as important factors determining the human behaviour (Zou et al., 2020) in pedestrian accidents with vehicles analyzed using SEM. This approach is one of the most robust analytical methods in social sciences research that enables the study of latent variables. SEM is one of the most robust analytical methods in social sciences research and enables investigation of latent variables (Benitez et al., 2020; Henseler & Chin, 2010; Tarka, 2018). One of the core advantages with SEM is that it examines the factor structure and structural relations in one coherent model, i.e. combines factor analysis and regression analysis. With this method it is possible to examine the relationship between observed and latent variables, which leads to a better evaluation of the model than other conventional methods such as regression analysis.

2. Literature review

Thus far, several studies have been conducted on the causes of accidents using accident-based statistics, most of which have focused on accidents occurring in urban areas, especially intersections (Al-Ghamdi, 2003; Hongqi, 2013; Layegh et al., 2020; Potoglou et al., 2018; Shesterov & Mikhailov, 2017; Tian, 2013; Sheykhfard et al., 2020). On the other hand, although different statistical approaches have been used for data analysis, most of the approaches have used conventional regression methods. A number of these studies are listed in Table 1.

Also, there have been rather few studies using SEM on road safety in comparison with other conventional methods, although the application of this approach is increasing due to its features. Zhou et al. (2016) studied traffic violations among pedestrians in Dalian city in China using three components including perceptions of behavioural control, subjective norms, and risk perception. They used a questionnaire with a scenario where pedestrians crossed the road violating the pedestrian lights at an intersection. The results of the SEM showed that the presence of other pedestrians is highly influential on individual (Zhou et al., 2016). Hassan and Abdel-Aty (2011) conducted a study in the United States and used SEM to identify factors associated with young drivers' involvement in at-fault crashes or traffic situations. In this research, the effects of observed variables such as demographics and aberrant driving behaviours were analyzed through two exogenous variables: (a) in-vehicle distractions, and (b) aggressive violations on the dependent variable as an endogenous variable. The results showed that aggressive violations, in-vehicle distractions, and demographics were significant factors affecting young drivers' driving behaviour (Hassan & Abdel-Aty, 2011). Al-Mahameed et al. (2019) reviewed reports and statistics of pedestrian and cyclist accidents in the United States from 2009 to 2016. A total of 60 variables were investigated in 200 highway corridors to determine the relationships between observed and latent variables. The results of the SEM showed that the most influential variable in accidents was poor design of bicycle and pedestrian facilities (Al-Mahameed et al., 2019). Lefrandt et al. (2016) proposed and tested the Pedestrian Satisfaction Model with a SEM approach. They used pedestrian traffic data using simple sampling and SEM. The results showed that management aspect (performance) technical aspects of transport and facilities (endurance), and quality of service (attention) affected the satisfaction of pedestrians' facilities. Management aspects had the greatest impact on pedestrians' satisfaction (Lefrandt et al., 2016). Another study examined perception of risk, concern, and behaviour of pedestrians in Norway using SEM. The results showed that pedestrians considered their risks as more severe and they were more worried about being exposed to risks at night compare to day time (Kummeneje & Rundmo, 2019).

Previous studies mainly applied logistic regression methods, in which the impact of some influencing factors on the final model cannot be identified. These limitations include the effect of latent variables that cannot be identified by evaluating the manifest variables. Furthermore, logistic regression only allows variables to be either a dependent variable (DV) or independent variable (IV), and unlike SEM a variable cannot be both an IV and DV in the same analysis. Logistic regression analysis is also confined to solely include one DV. SEM analysis provided us with the opportunity to examine more complex relationships between the IVs and DVs and to integrate the factor analysis (measurement model) and structural relations (structural model) into one coherent model. One of the main advantages of using SEM is the ability to test theories in the form of equations between variables. Another reason for taking into account the measurement error by this method is that it allows the researcher to analyze the data by estimating the measurement error (Kupek, 2006). Conventional models in

Table 1. Previous studies of pedestrian accidents.

Author, year	Research subjects (country)	Variables	Samples	Results
(M. G. Mohamed et al., 2013)	Consequences of the severity of pedestrian injuries (America and Canada)	Traffic control, lighting, type of vehicle, type of land use	Data for 2002–2006	The results showed that pedestrian age, type of location, age of driver, type of vehicle, and use of alcoholic beverages were factors that had significant effects on accidents.
(Aziz et al., 2013)	Deterministic factors of accidents on the sidewalks (USA)	Road characteristics, traffic characteristics, and land use	unknown	This research showed that the countermeasures for each region and different settlements were different. The priority of countermeasures should also be different.
(Abay, 2013)	Examining the severity of pedestrian injuries (Denmark)	road user characteristics	Data for 1998–2009	The empirical analysis revealed that detailed road user characteristics such as crime history of drivers and momentary activities of road users at the time of the accident provide an interesting insight in injury severity analysis.
(Araar & El Tayeb, 2013)	Mining road traffic accident data to improve safety in Dubai (UAE)	Age and gender of pedestrian, Driver's skill, Type of vehicle, Alcohol and drug use, Weather conditions	Unknown	The driver's insufficient control of the vehicle and the lane change, the pedestrian's lack of attention to the traffic status before movement, and the lack of sufficient distance between the pedestrian and other vehicles were the major causes of the crash.
(Aidoo et al., 2013)	The effect of road and environmental characteristics on pedestrian accident(Ghana)	road and environmental characteristics	Data for 2004–2010	Factors that exacerbate accidents include lighting, weather conditions, road pavement, road separation tools, and the location of accidents.
(Khattak & Tung, 2015)	Severity of Pedestrian Crashes at Highway-Rail Grade Crossings (USA)	Investigation of the role of traffic and the geometrical and environmental conditions of the routes on pedestrian accidents	Four-year accident statistics	Lack of considering the principles to standardize the proper I / O joint of business centers and the existence of multiple lanes on the routes, leading to the interference area between vehicles intending to stop on the lane and other vehicles traveling at the maximum permitted speeds.
(Oikawa & Matsui, 2017)	Features of serious pedestrian injuries in vehicle-to-pedestrian (Japan)	Vehicle type, travel speed, gender, and pedestrian age	Data for 1999–2009	The result of the study shows that pedestrian injuries are often from the waist down in passenger cars and at low speeds, but at high speeds, there is more injury to the bones and head injuries.
(M. Mohamed & Bromfield, 2017)	Investigation of Young Drivers' Behavior in Road Accidents (Kingdom of Saudi Arabia)	attitudes, driving behaviours, and accident involvement	287 Driver Behavior Record Data	Driving with unpermitted speed on different routes, overtaking on the lane, and failing to comply with traffic regulations such as passing a red traffic light is among the high-risk behaviours that can eventually lead to an accident.
(Huang et al., 2018)	A study on the correlation of pedestrian head injuries with physical parameters (China)	A detailed record of head injury severity	43 accidents	The determined brain injury predictor and tolerance were suggested for assessment of vehicle safety performance.
(Värnild et al., 2020)	Examine pedestrian accident in urban road (Sweden)	Pedestrian body	403	Pedestrians were mostly injured in the lower parts
(Thomas et al., 2020)	Epidemiology of pedestrian fatalities (USA)	Alcohol and drugs	1781	Five drug classes detected; stimulants, cannabinoids, narcotics, depressants, and Other Drugs.
(D. Wang et al., 2019)	Accident severity analysis (China)	Human damage and case fatality rate	NA	The two variables show the growing accident severity in China from a new viewpoint.
(Verzosa & Miles, 2016)	The severity of road crashes (Philippines)	Pedestrian and environmental characteristics	7628	Most pedestrian fatalities occur on high-speed, high-traffic-volume, multilane roadways
(Etehad et al., 2015)	Impact of road traffic accidents on the elderly (Iran)	Age	1306	Pedestrians over the age of 65 are the most vulnerable. The injuries and casualties of this age can be attributed to their physical and visual disabilities.
(Nowakowska, 2014)	Evaluation of threat for pedestrian accidents (Poland)	Drug and Alcohol	4000	High-risk behaviours were also observed in pedestrians, including sudden direction changes across the street without regard to traffic congestion.
(Theofilatos & Efthymiou, 2012)	Pedestrians' Accident Patterns (Greece)	Personal attributes, as well as other recorded characteristics of the accident	206	The severity of the crashes was different for the two young and old age groups
(Sullivan & Flannagan, 2011)	Differences in the geometry of pedestrian crashes (USA)	Daylight or dark conditions	400	There is a difference because of affecting the characteristic asymmetry of low-beam headlamps
(Kong & Yang, 2010)	Pedestrian casualty risk (China)	Pedestrian's age and vehicle's speed	104	Both variables affect fatalities statistics
(Wanvik, 2009, pp. 1987–2006)	Effect of road lighting on accidents (Netherlands)	Road lighting condition	763,000	Road lighting condition can reduce the likelihood of accidents

(continued)

Table 1. Continued.

Author, year	Research subjects (country)	Variables	Samples	Results
(Kim et al., 2008)	Driver and pedestrian fault (USA)	Human, temporal, roadway, and environmental factors	2231	Age and alcohol consumption by pedestrians as well as driver age were important factors in the probability of accidents
(Sze & Wong, 2007)	Model for pedestrian injury severity (China)	Pedestrian behaviour, traffic congestion, and junction type	73,746	The impacts of pedestrian behaviour, traffic congestion, and junction type on pedestrian injury risk are temporary.
(Al-Madani & Al-Janahi, 2006)	Analyze pedestrian injury accidents (Bahrain)	Type of the accident, gender, age, nationality, and educational background of the victims.	485	Personal and social backgrounds of pedestrians have a high impact on their vulnerability risk in accidents.
(C. Lee & Abdel-Aty, 2005)	Analysis of vehicle-pedestrian crashes at intersections (USA)	Drivers and pedestrians, and traffic and environmental characteristics	7000	Pedestrian and driver demographic factors and road geometric, traffic and environment conditions are closely related to the frequency and injury severity of pedestrian crashes.
(Ballesteros et al., 2004, pp. 1995–1999)	Pedestrian injuries (USA)	Pedestrian and traffic characteristics	3368	The speed of the car was the most important factor in the probability of an accident
(Zajac & Ivan, 2003)	Effect of roadway and area type features on injury severity of pedestrian crashes	Environmental characteristics	9-year accident statistics	The severity of the pedestrian injuries varied according to the accident area
(Al-Ghamdi, 2002)	Pedestrian–vehicle crashes (Saudi Arabia)	Factors recorded in the accident database	638	Crossing unmarked areas was one of the main causes of pedestrian accidents
(Simončič, 2001)	Analyze road traffic accidents (Slovenia)	Drivers and pedestrians, and traffic and environmental characteristics	2247	Pedestrians and motorcyclists are at higher risk than cyclists
(Abdel-Aty & Abdelwahab, 2000)	Examining the differences in an alcohol-related accident (USA)	Alcohol consumption	50641	The 25–34 age group experience the highest rate of alcohol/drug involvement in accidents.

structural equation modeling (SEM) consist of two parts. The first is a measurement model that examines how latent variables are explained by manifest variables (questionnaire items) and the second is a structural model that shows how latent variables are related to each other. There are other advantages to using structural equation modelling, four of the most important of which are: (a) estimation of multiple relationships, (b) ability to measure latent variables (unobserved variable), (c) calculation of measurement error, (d) ability to examine the effect of multicollinearity. According to the cited studies, it can be concluded that investigating factors associated with pedestrian accidents on urban, suburban, and rural roads to identify latent and observed variables has not been addressed so far in a comprehensive study. Therefore, the results of the present study can lead to a better understanding of potential precursors of accidents that have so far been neglected studies using accident database data to analyze pedestrian accidents.

3. Materials and methods

3.1. Structural equation modelling (SEM)

SEM is a multivariate statistical analysis technique that is used to analyze the structural relationship between measured variables and latent constructs. A SEM consists of two components: a SEM that specifies the structural relations between latent variables and a measurement model that defines the relationships between latent variables and observed variables (Sheykhfard & Haghighi, 2020a). Latent variables and observed variables are two basic concepts in statistical analysis, in particular the discussion of factor analysis and SEM. Latent variables, also known as the exogenous variable, are variables that are not directly measurable. For this purpose, researchers use observed measures or items that form the questions of the questionnaire to measure latent variables.

3.2. Study location

The purpose of this study was to investigate the behaviour of pedestrians in traffic accidents on the roads of the Gilan province in Iran. In this regard, information was obtained about 1359 pedestrians who had died in a pedestrian accident between the years 2012 to 2017 on the roads of Gilan province from the Iranian Legal Medicine Organization.

3.3. Variables

The variables that were recorded in pedestrian and motor vehicle accidents based on the Iranian Legal Medicine Organization report are shown in Table 2. Considering that many researchers argue that there should be at least 10 observations per variable (Austin & Steyerberg, 2015; Troutt, 2004), the sample size of the current study is in accordance with this criterion.

Table 2. Variables.

Observed variables		
Name	Description	Coding
Age	Pedestrian age	0–7: 1 7–18: 2 18–25: 3 25–50: 4 ≥50: 5
Gender	Pedestrian gender	Male: 1, Female: 0
V.Type	Vehicle type	Car (Pride): 1 Minibus: 2 Bus: 3 Pickup truck(Zamyad): 4 Truck: 5 Trailer: 6 motorcycle: 7 Bike: 8 Ambulance: 9 Agricultural machine: 10
C.Name	City name	Astara:1, Astana Ashrafieh:2 Amlash:3, Masal:4 Talesh:5, Bandar Anzali:6 Rasht:7, Razvan Shahr:8 Rudbar:9 Rudsar:10 Siahkal:11, Someh Sara:12 Shaft:13, Fouman:14 Lahijan:15, Langrud:16
R.Type	Road type	Urban road: 1)Major Street, 2) Minor Street, 3) Alley, 4) Highway, 5) Intersection, 6) Square, 7) Ring road, 8) Bridge, 9) Underpass Suburban road: 1)Freeway, 2) Highway, 3) Ring road Rural road
Date	Crash date	January:1, February:2 March:3, April: 4 May:5, June:6 July:7, August:8 September:9, October:10 November:11, December:12
Time	Crash time	1. 6:00–12:00 2. 12:00–18:00 3. 18:00–24:00 4. 24:00–06:00
Year	Crash year	1. 2012 2. 2013 3. 2014 4. 2015 5. 2016 6. 2017 7. 2018
C.severity	Collision severity	Fatal:1, Injury: 0

4. Results

4.1. Descriptive statistics

Figure 1 shows descriptive statistics of accidents for variables presented in Table 1. The figure shows that the rate of accidents in suburban areas (71%) was higher than in urban (28.32%) and rural (0.08%) locations. Male pedestrians (77.33%) were also more likely to be involved in accidents than female pedestrians (22.67%). The highest fatality rate among age groups was in the group above 50 years (67.03%), and the majority of accidents occurred between12 p.m. and 6 p.m. (38.11%). In addition, the highest accident rate occurred on freeways (31.93%) and highways (28.77%), and also Pride (car) and Zamyad (pickup truck) had the highest rates among other vehicles involved in the accidents (69.83% and 14.27%, respectively).

4.2. Factor analysis

In this study, the SmartPLS software has been used for the SEM analysis. In the first step, the nominal variables introduced in Table 2 were converted to binary variables to evaluate the impact of different categories on each variable. For example, four binary variables were created for the variable of time: (1) 06:00–12:00, others: 0; (2) 12:00–18:00, others: 0; (3) 18:00–24:00, others: 0; (4) 24:00–06:00, others: 0. The same applies to other groups. In the next step, all variables were analyzed using factor analysis (EFA) through the varimax rotation. The results of KMO (0.72) and Bartlett's test (sig = 0.01) indicated that the data were suitable for factor analysis. Varimax rotation is a common technique, which attempts to minimize the complexity of the factors by making the large loadings larger and the small loadings smaller within each factor (Hatcher, 1994; J.-Y. Lee et al., 2008).

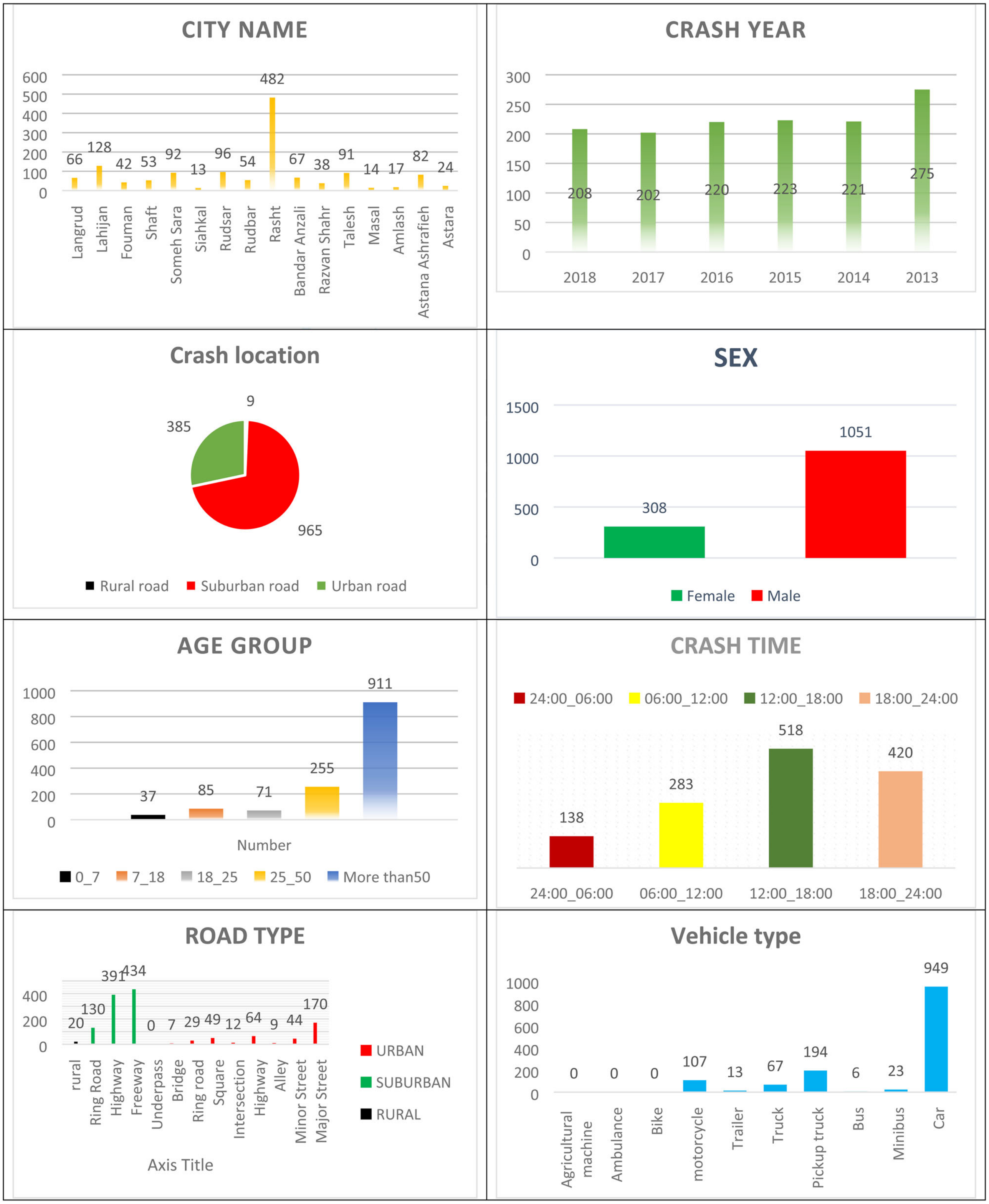

Figure 1. Descriptive statistics on pedestrian accident data.

In other words, varimax rotation is a statistical technique used at one level of principal component analysis (PCA) as an attempt to clarify the relationship among dimensions and to improve the interpretability of the correlation matrix. Generally, the process involves adjusting the coordinates of data that result from a PCA. The adjustment, or rotation, is intended to maximize the variance shared among items. By maximizing the shared variance, results more discretely represent how data correlate with each principal component. To maximize the variance generally means to increase the squared correlation of items related to one dimension, while decreasing the correlation on any other dimension. In other words, the varimax rotation simplifies the loadings of items by removing

Table 3. Varimax rotated factor analysis results.

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Age: 18–25	0.413	0.001	0.085	−0.019
Age: for ≥50	0.666	0.083	0.205	0.000
V.Type: Car (Pride)	0.002	0.571	0.000	0.008
V.Type: Pickup Truck (Zamyad)	−0.112	0.729	0.000	−0.007
R.Type: Urban (Major)	0.050	−0.005	0.806	0.111
R.Type: Urban (Intersection)	0.008	−0.014	0.911	−0.066
R.Type: Suburban (Ring road)	0.000	0.001	5.449	0.014
Time: 12:00–18:00	−0.213	0.088	0.011	0.774

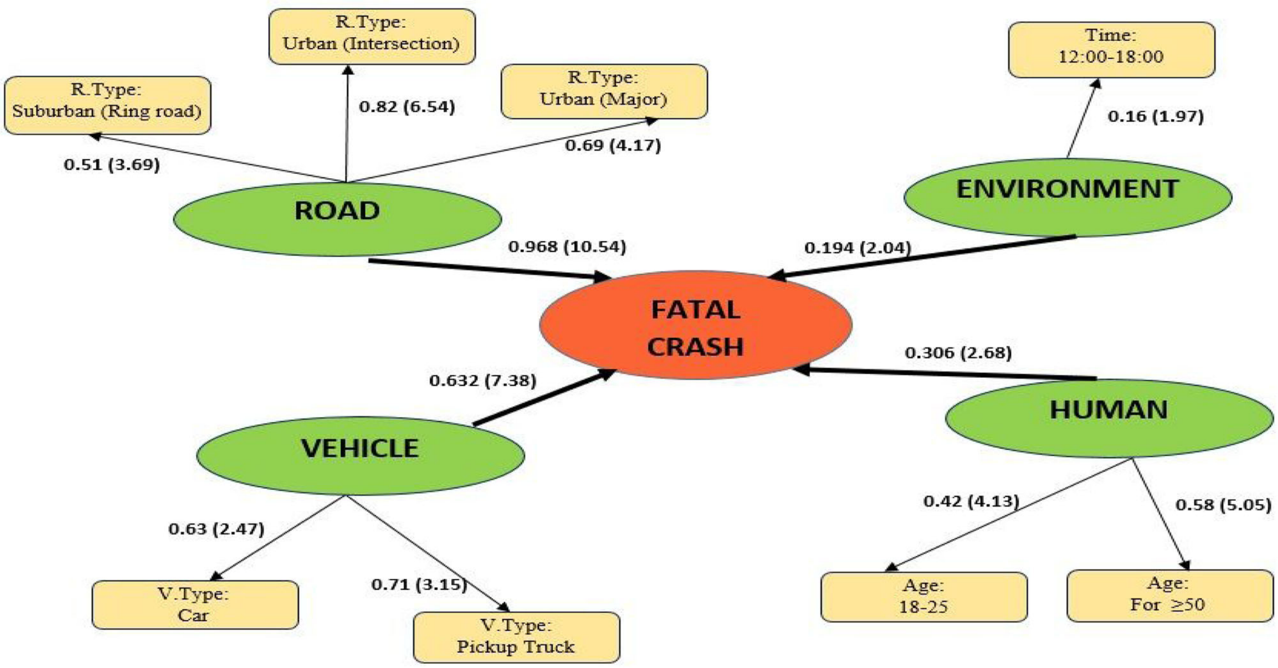

Figure 2. SEM of the fatal crash.

the middle ground and more specifically identifying the dimension upon which data load.

Based on this, in the present study, the process of linking observed variables and their dimensions through varimax rotation is presented in Table 3. Two observed variables (Age: 18–25 and Age: for ≥50) were placed in the first dimension, named 'Human Factors'. Further, two variables (V.Type: Car (Pride) and V.Type: Picup Truck (Zamyad)) were segmented in the second dimension, named 'Vehicle Factors'. Then, three variables (R.Type: Urban (Major), R.Type: Urban (Intersection), and R.Type: Suburban (Ring road)) were placed in the third dimension, named 'Road Factors'. Also, one variable (Time: 12:00–18:00) was segmented in the fourth dimension, named 'Environmental Factors'.

Table 3 shows the result of this process. Among all the variables presented in Table 2, only eight variables were identified as influencing variables in the final model and these variables were categorized into four latent factors.

In the present study, the pedestrian accident risk was considered as an endogenous latent variable that was influenced by latent (exogenous) variables of human as well as vehicle, road, and environmental factors. The latent variable of human factors was measured by the observed variables of pedestrian age, latent variable of vehicle factors by the observed variable of the type of vehicle, latent variable of road factors by observed variable of road type and latent variable of environment factors by the observed variable of accident time. Finally, the final model contained four exogenous variables and one endogenous variable, which was based on some observed significant variables. This model is shown in Figure 2.

A SEM model of fatal crashes is presented in Figure 2. Numbers on arrows and numbers in parentheses represent estimated coefficients and *t*-values for the variables, respectively. Based on this, any increase in each of the exogenous variables is associated with an increase in the probability of the endogenous variable (fatal crash). In the structural model, coefficients of the effect of four exogenous variables, namely, human factors, road factors, environmental factors, and vehicle factors, on the target variable were obtained as 0.306, 0.968, 0.194, and 0.632, respectively. Regarding coefficients, road and vehicle factors were the most significant factors on fatal crash. Therefore, although human and environmental factors are significant, management of causation variables related to road and vehicle factors can make greater influence on reducing the probability of fatal crash. Also, the results showed that, in terms of road factors, all three observable variables had a positive effect on fatal crash.

Table 4. Cronbach's a-value and AVE value.

Latent Variable	Observable Variable	Reliability		Convergent validity	
		Cronbach's a	Composite reliability	AVE	>0.5
Road	R.Type: Urban (Major)	0.812	0.871	0.618	✓
	R.Type: Urban (Intersection)	0.862			
	R.Type: Suburban (Ring road)	0.885			
Vehicle	V.Type: Car	0.762	0.793	0.640	✓
	V.Type: Pickup Truck	0.802			
Human	Age: 18–25	0.742	0.772	0.532	✓
	Age: For ≥50	0.782			
Environment	Time: 12:00–18:00	0.822	0.842	0.595	✓

Evaluating the data shows that the non-standardization design of intersection (coefficient: 0.82) and major road (coefficient: 0.69) in urban roads as well as ring road in suburban roads (coefficient: 0.51) leads to an increase in the severity of accidents. These defects are mainly related to the inadequacy of the road design system such as safe sight distance as well as the road lighting system. Regarding the human factor, two variables (Age: 18–25 (coefficient: 0.42) and Age: for ≥50 (coefficient: 0.58)), are directly related to the increase in the probability of accidents. In these groups, the use of speeding as well as risky behaviours such as unauthorized overtaking increases the likelihood of death in an accident. The positive coefficients of, Car (Pride) (coefficient: 0.63) and Pickup Truck (Zamyad)(coefficient: 0.71), as the main variables of V.Type show that the probability of the severity of accidents involving those types of vehicle increases fatal crash. There is an interval that may be due to the fatigue of drivers in this interval or the light condition of the road as the reasons. Also, the coefficient of Time variable for time interval between 12:00 and18:00 (coefficient: 0.16) shows that the majority of accidents in this period have resulted in death in this period. A SEM model of fatal crashes is presented in Figure 2. Numbers on arrows and parentheses represent estimated coefficients and *t*-values for variables, respectively (Figure 2). Based on this, any increase in each of the exogenous variables is associated with an increase in the probability of the endogenous variable (fatal crash). In the structure model, coefficients of the effect of four exogenous variables, namely, Human factors, Road factors, Environmental factors, and Vehicle factors, on the target variable were obtained as 0.306, 0.968, 0.194, and 0.632, respectively. Regarding coefficients, road and vehicle factors were the most substantial factors for fatal crashes. Therefore, although human and environmental factors are significant, management of causation variables related to road and vehicle factors can make greater influence on reducing the probability of fatal crashes. Also, the results showed that, in terms of road factors, all three observable variables have a positive effect on fatal crashes.

Evaluating the data shows that the non-standardized design of intersections (coefficient: 0.82) and major roads (coefficient: 0.69) in urban roads as well as ring roads in suburban areas (coefficient: 0.51) are associated with an increase in the severity of accidents. These defects are mainly related to the inadequacy of the road design systems, such as safe sight distances as well as the road lighting system. Regarding the human factor, the variable age (Age: 18–25 (coefficient: 0.42) and Age: for ≥50 (coefficient: 0.58)), is directly related to an increase in the probability of accidents. In these groups, speeding as well as risky behaviours such as unauthorized overtaking increases the likelihood of death in an accident. The positive coefficients of Car (Pride) (coefficient: 0.63) and Pickup Truck (Zamyad) (coefficient: 0.71), as the main variables of V.Type show that the probability of the severity of accidents involving those types of vehicles increases the probability of fatal crashes. There is an interval that may be due to the fatigue of drivers in this interval or the light conditions of the roads as the reasons. Also, the coefficient of Time variable covering the time interval between 12:00 and18:00 (coefficient: 0.16) shows that the majority of accidents have resulted in death in this time interval.

4.3. Assessing model

The evaluation of the final model can be divided into three general parts: measurement model evaluation, structural model evaluation, and overall evaluation of the final model. The results of all indicators used have been shown in Table 4. The following is an introduction to these indicators and whether they met the conventional cut-off criteria for model-data fit as well as their corresponding values in the present research model.

4.3.1. Evaluation of the measurement model

The Cronbach's alpha coefficient indicator is used to evaluate the reliability of the indexes in the measurement model. It is a coefficient of consistency measuring how well a set of variables or items measures a single, unidirectional latent construct (Ma et al., 2010). Internal consistency indicates the degree of correlation between the factor and its related items. Cronbach's alpha values above 0.7 usually indicate acceptable reliability. In the present model, the alpha coefficient for all latent variables was higher than 0.7, indicating satisfactory reliability of the measurement model. The second criterion for evaluating the measurement model is convergent validity, which examines the correlation of each factor with its indicators. The average variance extracted (AVE) criterion represents the mean of the variance shared between each factor with its items. Simply put, AVE shows the correlation of a factor with its items and, the fit is higher as the correlation is higher. In an adequate model, AVE should be greater than 0.5 (Chin, 1998; Höck & Ringle, 2006), which means that factors should explain at least 50% of the total variance of their respective indicators. According to Table 4, for all the variables of the present model, the AVE value is greater than or equal to 0.5.

4.3.2. Evaluation of the structural model

Several criteria are used to investigate the goodness of fit of the structural model, the most basic of which is *t*-values (Structural path coefficients). This criterion is defined for measuring the relationship between the factors in the model. If the *t*-value is higher than 1.96 it shows that the result is significant at the 95% level. It should be noted that the numbers represent only the accuracy of the relationship and the strength of the relationship between factors cannot be measured with it. The results show that the variables in the final model (Figure 2) were significant at the 95% level on the likelihood of a pedestrian-related accident.

The R^2 index shows the extent of variation in endogenous variables resulting from exogenous variables. R^2 is a criterion indicating the effect of an exogenous factor on an endogenous factor and three values of 0.19, 0.33, and 0.67 are considered as the criterion for weak, moderate, and strong values. In the present study, according to the output of the final model, the value of R^2 for the model-dependent factor is strong (0.818) and the criterion value supports the suitability of the structural model.

The third indicator for evaluating the structural model is the Q^2 criterion which is related to the predictive power of the model. Some researchers believe that models that have acceptable factor analysis model fit should be able to predict items associated with model-dependent factors (Henseler & Chin, 2010). This means that if the relationships between the factors are correctly defined in one model, the factors will be able to influence each other's items sufficiently. The value of Q^2 must be calculated for all dependent factors of the model. If the value of Q^2 for a dependent factor is zero or less than zero, it indicates that the relationships between the other factors of the model and that dependent factor are not well explained and as a result, the model needs to be respecified. This criterion specifies the predictive power of the model and if the Q^2 value for one of the endogenous factors has three values of 0.02, 0.15, and 0.35, it respectively indicates weak, medium, and strong predictive power, for the factor or its exogenous factors. In the present study, the value of the Q^2 index for the model was 0.41, indicating that the (independent) exogenous factors predict the dependent factor and again support the appropriate fit of the structural model.

4.3.3. Overall evaluation of the model

Two indicators of the Normed Fit Index (NFI) and Standardized Root Mean Square Residual (SRMR) are used to evaluate the overall fit of the SEM model. NFI is an incremental measure of goodness of fit for a statistical model, which is not affected by the number of parameters/variables in the model (Hu & Bentler, 1998). In general, values above 0.8 indicate a feasible fit of the model to the data. On the other hand, the RMSEA index is one of the main indicators of goodness of fit in structural equation modelling.

The SRMR is defined as the difference between the observed correlation and the model implied correlation matrix. In many sources, values below 0.05 indicate a good fit to the model, although values below 0.08 have also been reported as acceptable. The values of these two criteria for the present model are 0.929 for the NFI index and 0.031 for the RMSEA index, respectively, indicating that the final model has appropriate fit.

5. Discussion

The analysis of eight observed exogenous variables was performed to determine the effect of the variables on the pedestrians' fatal accidents. Each of these variables was subdivided into several independent variables and finally, factor analysis showed that out of eight general variables (including 68 independent variables), eight independent variables as four latent exogenous variables had a significant relationship with pedestrian fatal accidents (endogenous variable). The four latent exogenous variables are the factors of road, vehicle, human, and environment.

5.1. Road

Although the human factor has been argued to be the most important cause of road accidents in official reports and various studies (Mako & Szakonyi, 2016; M. Mohamed & Bromfield, 2017; Papadimitriou et al., 2016; Quimby & Watts, 1981; Reeves et al., 2019; Transportation Research Board & National Academies of Sciences, Engineering, & Medicine 2014), some studies have also reported road (Ackaah et al., 2020; Daniels et al., 2010; Distefano et al., 2018; Vignali et al., 2019), vehicle (George et al., 2017; Han, 2013), and environment (Abdul Manan et al., 2018; Vignali et al., 2019; Y. Wang & Zhang, 2017) variables as critical causes of accidents. Considering the variables extracted from the accident database, the results of data analysis showed that the impact of the road factor on the occurrence of accidents may be more substantial than other variables. According to the results, intersections and major road in urban areas, as well as ring roads in suburban areas are the most high-risk areas where most accidents have occurred. It seems that these areas as accident hotspots should be specially studied in future studies to identify safety problems.

5.2. Vehicle

Today, technology advances in the automotive industry have led to competition among various automotive companies to provide up-to-date and safe services around the world (Jabbari et al., 2018, 2019; Khaloei et al., 2019). The use of new facilities along with systems to reduce the risk of accidents or even the severity of accidents in the event of an accident are the most important competitive aspects in this field. However, in many middle-income countries, such as Iran, vehicle safety is still one of the major problems – which increases the likelihood of fatal accidents. In the present study, the significant effect of two types of vehicles on the probability of fatal pedestrian accidents was identified which are Iranian productions. The lack of new facilities due to adverse economic conditions and the existence of various sanctions in the industry in recent years has led to the continued production of these vehicles in Iran. However, according to the latest information from the – automaker company of these vehicles, production of one of them is expected to stop next year but it is important to note that the use of up-to-date equipment in the automotive industry should be of interest to automakers not only in Iran but also in other developing countries. The two mentioned cars, which are domestically produced in Iran, have been involved in various accidents for many years.Improper design of the car, which reduces the driver's vision especially during turning manoeuvres, as well as weak braking systems are among the most important aspects that make their performance inadequate. Therefore, it seems that improving the braking system of vehicles may increase the safety of pedestrians through timely proper reaction of drivers or at least reduce the severity of the collision.

5.3. Human

Human beings may increase the likelihood of road accidents through errors, mistakes, unintentional and intentional offenses. The result showed that in all five groups, -age ranges of 18–25 and those more than 50 years old are more prone to fatal accidents. Although, no information about the pedestrian behaviour is available from data accident databases, however, the physical characteristics and behavioural tendencies of these age groups cannot be ignored. Previous studies have also reported physical disability (Lipovac et al., 2013; Salamati et al., 2014) in older age groups as well as pedestrians' willingness to cross through aggressive behaviours such as running (Habibovic et al., 2013; Sheykhfard & Haghighi, 2019, 2020b) or zigzag movements (Kadali & Vedagiri, 2013; Nuñez Velasco et al., 2019; Serag, 2014; Sheykhfard & Haghighi, 2018) in younger age groups. In this situation, it is possible to increase awareness of pedestrians as well as drivers through the information of high-risk or potentially dangerous behaviours.

5.4. Environment

The effect of this factor on the occurrence of fatal accidents through the independent variable of time was found to be significant. Examination of vehicle traffic in the studied routes indicates that the highest volume of traffic is present in the routes in the interval of 12:00–18:00.

6. Summary and conclusion

In the present study, data from 1358 pedestrian accidents from 2012 to 2018 on different roads of the Gilan province, Iran were analyzed using SEM. The purpose of this study was to assess the safety status of pedestrians on the urban, suburban, and rural roads in16 different cities in the Gilan province. The effect of the probability of eight observed variables extracted from the data from the Iranian Road Police Accident Database in the form of 68 independent variables on occurring damages towards pedestrians was thoroughly discussed. SEM supports the role of four exogenous variables affecting fatal accidents among pedestrians. It turned out that the main four parameters of interest in the order of importance are road, vehicle, human, and environment.

Concerning the road factors, three independent variables had a meaningful effect on the dependent variable of model. These three variables were intersections, main roads, and ring roads which respectively concern urban, urban, and suburban areas. The results stated that most fatal accidents are in these areas in which this highlights the importance of current analysis. In addition to this factor, the vehicles do have a pivoting role on the fatal accidents which also highlights the effect of two main vehicle manufacturers in Iran. The two kinds have problems such as braking flaws which are instrumental in shaping the probability of fatal accidents. Another important parameter was pedestrians' age on the accidents. It was shown that the probability of accident occurrence is not the same across different age groups. Each of the different age groups has different physical characteristics and abilities, which is a major challenge in analyzing environmental conditions and road users while deciding on the performance of the drivers. This parameter has the potential for being implemented as a potential prerequisite in training courses for a driver's license. In addition to the above-mentioned factors, time is another variable of interest which denotes the need to analyze the amount of traffic at different times of the day.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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