Analysis of Studies on Traffic Crashes Involving the Elderly

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Analysis of Studies on Traffic Crashes Involving the Elderly:

A survey of methods, influencing factors, and perspectives

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Abstract: Ageing is an inevitable trend of population development. It is vital to study the traffic safety of elderly populations. Although much literature has been produced about this issue, problems such as an inconsistent definition of the elderly and scattered research objectives still exist. This study uses crash data analysis to find the conclusions, limitations and development directions of this research by retrieving accident analysis studies of the elderly from 2015 to the present. This study reviews crash analysis methods and crash characteristics and crash-influencing factors among the elderly. Most of the current studies analysing traffic accidents in the elderly come from the United States, China and Korea. The literature typically defines the elderly as those above 60 or 65 years old. Common research methods include statistical and machine learning methods. Key factors influencing traffic safety among the elderly are factors related to crash victims, vehicles and the road environment. Future research directions are proposed to investigate the heterogeneity of elderly populations in greater depth.

1. INTRODUCTION

An ageing society is upon us, as the so-called ‘baby boomer’ generation, born in the population boom of the 1940s and 1950s, begin to reach their golden years (Fildes, 2006). The universally accepted criteria for entering an ageing society are those formulated by the United Nations in 1956 and the World Assembly on Ageing in 1982: either the proportion of the population aged 60 and above should reach 10.00%, or the proportion of the population aged 65 and above should reach 7.00%. Globally, the world's ageing trend is obvious. According to the World Bank, the global elderly population aged 65 and over reached 7.04% in 2002 and 9.40% in 2020 (Liu, 2021). Of course, the development trend of each country varies. By 2020, the population aged 60 or above in China had reached 264 million, with an annual increase of tens of millions (Chen, Long and Felkner, 2020; Wang, W., Fu et al., 2022).

Furthermore, with 34.3% of the population aged 60 or above, Japan is the oldest country in the world; in European countries such as France and Germany, more than 25% of the population is aged 60 or older (Liu, 2021). According to the US Census Bureau, the proportion of the US population aged 65 and above will reach 20% by 2030 (Giuliano, Hu et al., 2003).

Given these trends, scholars are concerned about the derivative problems of an ageing society, especially traffic safety for elderly road users. Numerous studies have shown an increase in crashes among older drivers over the age of 65 (Bélanger, Gagnon et al., 2010; Lee, J. and Gim, 2021; Rakotonirainy, Steinhardt et al., 2012; Wei, Huang et al., 2020). For example, the Korean Road Traffic Authority has found that the number of traffic crash fatalities by elderly drivers (aged over 64) in South Korea increased by 34.7% between 2011 and 2015 (Lee, J. and Gim, 2021). Traffic crashes are the second leading cause of death after falls for people over 60 (Wei, Huang et al., 2020). Additionally, the elderly present more severe injuries in traffic crashes (Ayuso, Sánchez et al., 2020; Lee, J. and Gim, 2021; Wei, Huang et al., 2020). As people age, risk factors for traffic crashes include their poor ability to deal with complex traffic conditions, poor driving stability and slow reaction time, especially at intersections (Bélanger, Gagnon et al., 2010).

Many researchers have investigated the influencing factors of crashes in the elderly (Al Mamlook, Abdulhameed et al., 2020; AlKheder, AlRukaibi et al., 2020; Amiri, Sadri et al., 2020; Casado-Sanz, Guirao et al., 2019; Haule, Sando et al., 2019; Kim, D., 2019; Kim, Sungyop, Ulfarsson et al., 2019; Noh, Kim et al., 2018; Pan, Wu et al., 2022; Park, Choi et al., 2021; Wen, Qu et al., 2021; Yuan, Q., Zhang et al., 2022; Yuan, Z., Guo et al., 2022), the spatial and temporal distribution characteristics of the elderly-involved accidents (Cardona, Arango et al., 2017; Chang, Li et al., 2020; Etehad, Yousefzadeh-Chabok et al., 2015; Freitas, Bonolo et al., 2015; Kang, Cho et al., 2018; Lee, J. and Gim, 2020; Nishino, 2013; Prochowski, Gidlewski et al., 2018; Sadeghi-Bazargani, Samadirad et al., 2018; Sagar, Stamatiadis et al., 2020; Setiawan, 2021), safety awareness and risk cognition of the elderly (Doi, Ishii et al., 2020; Guo, Shi et al., 2018; Hamido, Hamamoto et al., 2021; Handa and Mitobe, 2020; Huseth-Zosel and Hammer, 2018; Jian and Shi, 2020; Laosee, Rattanapan et al., 2018; Makizako, Shimada et al., 2018; Nakagawa, 2019; Nishiuchi, Park et al., 2021; Pulvirenti, Distefano et al., 2020; Söllner and Florack, 2019; Uchibori, Handa et al., 2021). Using traditional traffic safety analysis methods, scholars have analysed the relationship between the number or severity of crashes and various factors involving human error, vehicles and the road environment to find the cause of accidents. With the development of new technologies and the convenience of information collection, some scholars have begun to use driving simulators or questionnaires to explore driving behaviours and traffic safety awareness among the elderly. However, some scholars have questioned the validity of the resulting findings. Ultimately, the crash-based analysis method is still the most recognised and reliable analysis method.

Although many studies have been conducted on traffic crashes among the elderly, the relevant research remains separated and scattered due to variances in research objectives. By summarising and analysing existing literature, we hope to obtain a clear overview of the issue and provide support for subsequent traffic safety studies for the elderly by asking the following questions:

(1) What is the basic information collected in elderly crash analysis studies (the definition of 'elderly', aspects of the analysis, data used and the distribution of the main study countries)?

(2) What are the main analysis methods of elderly crash analysis?
(3) What significant factors influence crashes involving the elderly?

The rest of this review is organised as follows. Section 2 presents the search strategy. Sections 3 to 5 review the basic information of elderly crash analysis studies, the main analysis methods used and the significant influencing factors of elderly crashes. Finally, Section 6 discusses future research directions in elderly crash analysis studies.

2. METHODOLOGY

In order to analyse the current status and future directions of research in crash analysis in the elderly, this paper conducts a literature review of existing research objectives, methods and problems. We obtained relevant studies published from 2015 to 2022 by searching the following keywords in several databases, including PubMed, Web of Science, Google Scholar, Scopus and ScienceDirect: 'elderly/older/aged/ageing', 'traffic accident/collision/crash', 'injury/crash severity'. This included common search commands such as (elderly OR older OR aged OR ageing) AND ('traffic accident' OR 'traffic collision' OR 'traffic crash' OR 'injury severity' OR 'crash severity').

The following strategies were used to filter the studies as shown in *Figure 1:* first, reading the title and abstract allowed studies mentioning age and accident/crash to be filtered; second, reading the full text allowed studies including older people and crash data analysis to be filtered. Studies covering all ages, or those based on other data sources, such as questionnaires and driving simulators, were eliminated. Among the literature, we found five literature reviews on the topic of traffic safety for the elderly (Ang, Chen et al., 2017; Azami-Aghdash, Aghaei et al., 2018; Fitzpatrick and O'Neill, 2017; Furtado, Lima et al., 2019; Jung, Meng et al., 2017). These review the following five aspects, respectively: the influencing factors of road traffic crashes in older adults, epidemiological models and interventions to prevent road traffic injuries among the elderly, trends and factors in ageing motorcyclists' collisions, demographic and sociological characteristics of the elderly injured in traffic crashes, and intelligent vehicle technologies to improve the driving experience of elderly road users. Ultimately, 53 studies were reserved for analysis after the above elimination, as listed in *Table 1*.

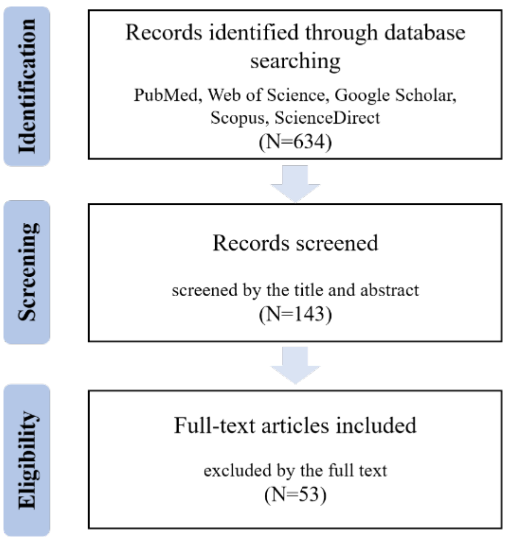

*Figure 1.*Flow diagram of the search strategies.

Table 1. Literature list

Reference	Research objective	Elderly definition	Country	Crash database
Adanu, Lidbe et al. (2021)	Investigate the factors contributing to the injury severity of crashes resulting from improper lane change manoeuvres among older drivers	65+	USA	Alabama, 2012-2016 (N=6,831) drivers
Adebisi, Ma et al. (2019)	Investigate the factors influencing motor vehicle crash injury severity for older drivers	65+	USA	California, 2005-2014 (N= 1,520,465) drivers
Al Mamlook, Abdulhameed et al. (2020)	Predict car crash injury severity among elderly drivers	60+	USA	Michigan, 2010-2017 (N=85,102) drivers
Alhomaidat, Abushattal et al. (2022)	Explore the interaction between age and liability for crashes at stop-sign-controlled intersections	65+	Jordan	Michigan, 2015-2019 (N =19,878) drivers
Amin (2020)	Explore the factors affecting traffic crashes of older female and male drivers	60+	UK	West Midlands, 2006-2016 (N=95,092: 29,465 female/65,627 male) drivers
Amiri, Sadri et al. (2020)	Compare methods of predicting the severity of fixed object crashes among elderly drivers	65+	Canada	California, 2012 (N=4,070) drivers
Ayuso, Sánchez et al. (2020)	Investigate the effect of driver age on crash severity	65+	Spain	Spain, 2016 (N=59,622) drivers
Boele-Vos, Van Duijvenvoorde et al. (2017)	Investigate the factors influencing the occurrence and consequences of elderly-involved bicycle crashes	50+	Netherlands	Netherlands, 2012 (N=136) cyclists
Bravo, Duarte et al. (2020)	Investigate the crash pattern and consequences of elderly-involved crashes	60+	Chile	Chile, 2008-2017 (N=144,054) injured in traffic accidents
Cardona, Arango et al. (2017)	Analyse traffic crash mortality in older Colombian adults	60+	Colombia	Colombia, 1998-2012 (N=100,758) drivers
Casado-Sanz, Guirao et al. (2019)	Explore the influencing factors of the severity of road crashes on Spanish crosstown roads	65+	Spain	Crosstown roads, Spain, 2006–2015 (N=1,405) pedestrians and drivers
Chen, Lihui and Wang (2017)	Investigate the risk factors of traffic crashes for different age groups	60+	China	California, 2010-2012 (N= 33,245) drivers
Darban Khales, Kunt et al. (2019)	Analyse the impacts of risk factors on the injury severity of older drivers	65+	USA	New Mexico, 2015-2016 (N= 29,347) drivers
Das, Bibeka et al. (2019)	Determine the key associations between the	65+	USA	US, FARS

Reference	Research objective	Elderly definition	Country	Crash database
	contributing factors of elderly pedestrian crashes			2014-2016 (N=3,422) pedestrians
Doi, Ishii et al. (2020)	Examine the association between car crashes, frailty and cognitive function in car crashes involving older adults	60+	Japan	Obu and Takahama, 2015–2017 Toyoake and Tokai, 2017–2018 (N =12,013) drivers
Doulabi and Hassan (2021)	Analyse risk factors of crash severity for older drivers	65+	USA	Louisiana, 2014-2018 (N= 927) drivers
Etehad, Yousefzadeh-Chabok et al. (2015)	Investigate patterns of road traffic injuries in the ageing population	60+	Iran	Iran 2011-2012 (N=1,306) pedestrians and drivers
Gim (2022)	Investigate factors influencing the injury severity of traffic crashes involving older drivers	65+	Korea	Korea 2011-2015 (N = 89,712) drivers
Hamido, Hamamoto et al. (2021)	Investigate factors influencing the safety of older occupational truck drivers	50+	Japan	Japan 2015-2017 (N= 306: 131 old/175 young) drivers
Haule, Sando et al. (2019)	Investigate the proximity of crash locations to ageing pedestrian residences	65+	USA	Florida, 2008-2013 (N=1,068) pedestrians
Huseth-Zosel and Hammer (2018)	Determine whether differences exist in risky driving behaviours of veterans and non-veterans aged 65 or older	65+	USA	US, 2011 (N=1,583) drivers
Kang, Cho et al. (2018)	Analyse spatiotemporal characteristics of the elderly population's traffic crashes	65+	Korea	Seoul, Korea, 2013 (N=3,340/3,950) drivers/crash victims
Kitali, Kidando et al. (2017)	Evaluating crash severity among ageing pedestrians	65+	USA	Florida, 2009-2013 (N=1,628) pedestrians
Kim, D. (2019)	Identify the exclusive contributing factors to elderly pedestrian collisions at intersection	65+	USA	US, 2015-2017 (N = 13,844: 2,471 elderly and 11,373 younger) pedestrians
Kim, Seunghoon, Lym et al. (2021)	Predict the severity of crashes involving the elderly	65+	USA	Ohio, 2015–2019 (N=104,486) drivers
Kim, Sungyop, Ulfarsson et al. (2019)	Analyse patterns of crashes involving older pedestrians	65+	USA	US, 2012-2013 (N=408: age 65+/ 2,389 age 18 to 59) pedestrians

Reference	Research objective	Elderly definition	Country	Crash database
Kong, Hyun Kim et al. (2018)	Investigate the injury patterns of minor motor vehicle crashes by individual age groups	55+	Korea	Korea, 2011-2017 (N=136) elderly patients
Lalika, Kitali et al. (2022)	Investigate factors influencing the injury severity of crashes involving older pedestrians	65+	USA	Florida, 2016-2018, (N=913) pedestrians
Lee, D., Guldmann et al. (2019)	Investigate factors contributing to the relationship between driving mileage and crash frequency of older drivers	65+	Korea	Ohio, 2006 - 2011, (N=161,501) drivers
Lee, H. H., Cho et al. (2019)	Identify factors affecting the injury severity of elderly pedestrians-involved traffic crashes	60+	Korea	Korea, 2011- 2016, (N = 13364) pedestrians
Lee, J. and Gim (2020)	Examine the characteristics of elderly drivers' traffic crashes in urban areas	65+	Korea	Korea, 2015 (N= 3593) drivers
Lee, S., Yoon et al. (2020)	Investigate the impact of built environments on the risk of pedestrian crashes among the elderly	65+	Korea	Seoul, Korea, 2015-2017 (N= 32,051/6,661 elderly) pedestrians
Lee, H. Y., Youk et al. (2021)	Analyse factors affecting the prevalence of traumatic brain injury (TBI) in the elderly occupants of motor vehicle crashes	55+	Korea	Korea, 2011-2018 (N=822: TBI:357/non-TBI:465) pedestrians and drivers
Matsuyama, Kitamura et al. (2018)	Investigate the motor vehicle crash mortality of elderly drivers	65+	Japan	Japan, 2004 - 2015 (N=39,691) drivers
Ma, Lu et al. (2018)	Investigate factors influencing pedestrian injury severity at intersections	65+	China	Illinois, 2011-2012 (N=2,614) pedestrians
Momtaz, Kargar et al. (2018)	Investigate the rate and pattern of road traffic accidents among older drivers	60+	Iran	Iran, 2014-2015 (N = 2,646) drivers
Nishida (2015)	Analyse accidents to develop measures targeted at elderly drivers based on accident and violation records	65+	Japan	Japan, 1995-2013 (N = /) drivers
Noh, Kim et al. (2018)	Compare the influencing factors between younger-old and older-old pedestrian safety	65+	Korea	Seoul, Korea, 2008-2015 (N=79,078) pedestrians
Noh and Yoon (2017)	Investigate the confounding effect of occupant age in a vehicle in terms of seat position and seatbelt use	65+	Korea	Korea, 2008-2015 (N= 160,364) drivers

Reference	Research objective	Elderly definition	Country	Crash database
Palumbo, Pfeiffer et al. (2019)	Describe population-based rates of older drivers' licensing and per-driver rates of crashes and moving violations	65+	USA	New Jersey, 2010-2014 (N= /)
Pan, Wu et al. (2022)	Investigate the heterogeneous effects of the built environment on elderly crash injury severities	60+	China	Texas, 2016 (N=4,300) pedestrians and drivers
Park, Choi et al. (2021)	Investigate heatwave impacts on traffic crashes by time of day and age of casualties	65+	Korea	Korea, 2012-2017 (N=87,268) drivers
Pourebrahim, Bafandeh-Zendeh et al. (2021)	Investigate distracted behaviours of older male drivers in rear-end crashes	55+	Iran	Iran, 2018 (N= 395) drivers
Prochowski, Gidlewski et al. (2018)	Analyse changes in crash hazards for the elderly in road traffic	60+	Poland	Poland 2010-2016 (N= /)
Rapoport, Chee et al. (2021)	Investigate the impact of COVID-19 on motor vehicle injuries and fatalities in older adults in Ontario, Canada	65+	Canada	Ontario, 2018-2020 (N=5,380) drivers
Sadeghi-Bazargani, Samadirad et al. (2018)	Investigate the crash mechanisms and medical outcomes of traffic fatalities among the elderly	65+	Iran	East Azerbaijan, Iran, 2006–2016 (N = 9,435 / age > 65:1,357) pedestrians and drivers
Sagar, Stamatiadis et al. (2020)	Investigate the effectiveness of hospital-linked data to find the risk of elderly drivers being at fault in injury crashes	65+	USA	Kentucky GUM crash database, 2008–2014 (N =340,435 two-vehicle records)
Se, Champahom et al. (2020)	Compare driver injury severity in single-vehicle crashes based on age groups	50+	Thailand	Thailand, 2011-2017 (N = 9,877) drivers
Tseng, Hsieh et al. (2021)	Investigate the impacts and outcomes of elderly drivers involved in road traffic accidents	65+	China,Taiwan	Taiwan, 2009-2018 (N=2450) older patients
Wang, Y., Haque et al. (2017)	Investigate elderly pedestrian injuries in Singapore	65+	Singapore	Singapore, 2003-2008 (N=5,044) pedestrians
Wei, Huang et al. (2020)	Analyse injury mortality among the elderly over 60 years old	60+	China	Suzhou, 2008-2017 (N=2,318) injury mortality
Wen, Qu et al. (2021)	Investigate the factors influencing the severity of traffic crashes by elderly drivers	60+/60-80	China	Texas, 2016 (N=16,634) drivers
Yuan, Z., Guo et al. (2022)	Analyse risk recognition in traffic crashes involving older pedestrians	65+	China	Colorado, 2006-2016 (N=856) pedestrians

3. DEFINITION OF THE ELDERLY AND BASIC CHARACTERISTICS OF ELDERLY CRASHES

3.1 Definition of the elderly

Extracting the data set of elderly populations is the basis for analysing their traffic safety status and the influencing factors of elderly-involved crashes to ultimately identify the most effective safety improvement measures. Hence, defining the elderly is one of the most important factors of the analysis results. The World Health Organisation defines elderly people as those over the age of 60 (WHO, 2020). According to the Law of the People's Republic of China on the Protection of The Rights and Interests of the Elderly, China has the same definition. On the other hand, the UN defines the elderly as those over age 65 (Prochowski, Gidlewski et al., 2018). Across the literature, different definitions of the elderly are employed for various purposes of analysis. Some researchers analysed samples of people over 60 years old (Al Mamlook, Abdulhameed et al., 2020; Cardona, Arango et al., 2017; Doi, Ishii et al., 2020; Etehad, Yousefzadeh-Chabok et al., 2015; Pan, Wu et al., 2022; Wei, Huang et al., 2020; Wen, Qu et al., 2021). Some analysed specific age ranges, such as 60-80 years (Wen, Qu et al., 2021). Other researchers analyzed samples of people 65 years old and older (*Table 1*). Still others selected an age range starting at 50 years (Hamido, Hamamoto et al., 2021), 55 (Kong, Hyun Kim et al., 2018; Lee, H. Y., Youk et al., 2021) or 70years old (Nishiuchi, Park et al., 2021; Pulvirenti, Distefano et al., 2020). Although most scholars adopt 65 years as the standard to define the elderly, there is no uniformity and no comparison of differences between different samples. For the elderly, differences in physical health status, income, family situation, purpose of travel, regional economy, climate and road conditions may increase the heterogeneity of the sample. Therefore, attention should be paid to the impact of potential heterogeneity when selecting and analysing samples of the elderly.

3.2 Crash database

Given differences among the global ageing population, research into elderly-involved crashes naturally varies. In *Table 1,* we list the country of affiliation of the articles' first author. In order, these are the United States, Korea, China, European, Japan and Iran. In the above studies, scholars from various countries mostly use the crash data of their country to analyse the traffic safety of the elderly, except for Wen, Qu et al. (2021) and Yuan, Z., Guo et al. (2022). In the data listed in *Table 1*, there are two main data sources: one is the crash database of the local or regional traffic management department, and the other is the injury data of the local hospital or emergency centre. Depending on the availability of data and the quality of data in different countries, the sample sizes vary. Of the studies reviewed, 77% collected crash data across multiple years, and 21 studies evaluated the sample crash data of more than 10,000 subjects.

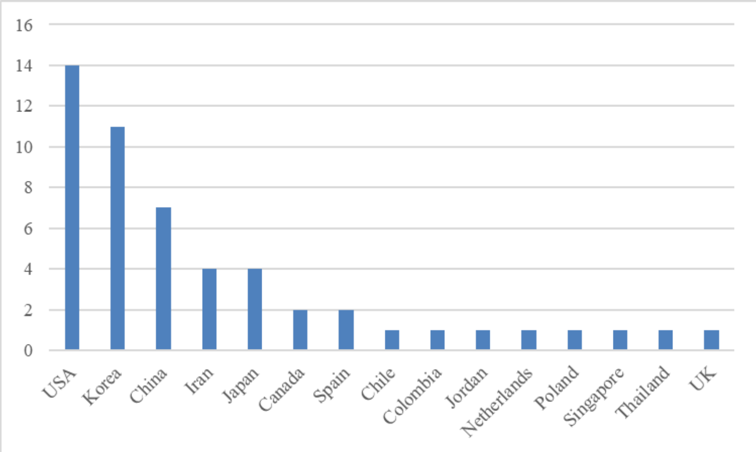

Figure 2. Distribution of author affiliation.

3.3 Basic characteristics of elderly crashes

Driving, walking and taking private cars or buses are the main travelling modes for the elderly. Traffic safety studies of the elderly are mostly analysed from two perspectives: the elderly as drivers and the elderly as pedestrians. Previous studies show that the number of elderly drivers is increasing, and the desire of older people to continue driving is very strong (Moon and Park, 2020; Shi and Jian, 2014). However, the risk of injury, especially serious and fatal injuries, is much higher for older drivers than for other age groups. Additionally, evidence shows that elderly pedestrians are the most vulnerable road users; they are more likely to be seriously injured than younger drivers and passengers (AlKheder, AlRukaibi et al., 2020).

In view of the above safety situation of the elderly, researchers have carried out studies on the patterns and temporal and spatial characteristics of elderly-involved crashes. Assessing crash severity, Ang, Chen et al. (2017) found that although only 18.5% of crashes involved people aged 60 and over, their risk of death was double that of other age groups. In addition, many scholars have reached the following conclusions: most of the elderly injured in traffic crashes are male (Ang, Chen et al., 2017; Etehad, Yousefzadeh-Chabok et al., 2015; Freitas, Bonolo et al., 2015), and elderly pedestrians constitute a large proportion of the total elderly injured (Prochowski, Gidlewski et al., 2018). As for the spatiotemporal characteristics of crashes among the elderly, Kang, Cho et al. (2018)) found that the spatial and temporal characteristics differ for crashes involving elderly pedestrians and those involving elderly drivers. The time and space distribution of crash hotspots is more concentrated for elderly drivers, and the hotspots are more obvious in hiking areas in spring and autumn, reflecting the travel preference of the elderly. Lee, J. and Gim (2020) found a higher risk of crashes involving older drivers in densely populated areas, such as business districts, job centres and subway stations.

4. ANALYSING METHODS OF ELDERLY CRASHES

Previous studies have provided a detailed review of the methods used in crashresearch (Lord and Mannering, 2010; Mannering, F., Bhat et al., 2020; Mannering, F. L. and Bhat, 2014; Savolainen, Mannering et al., 2011). There are three main categories of highway crash data analysis methods, traditional statistical methods (standard regression-based approaches), advanced statistical methods (such as models that account for unobserved heterogeneity), and data-driven methods (artificial intelligence, neural networks, machine learning, and so on) (Mannering, F., Bhat et al., 2020). The crash analysis methods for the can also be sorted into these categories, as shown in *Table 2*.

Table 2. List of methods

Analysis method	Reference
Statistical analysis	Boele-Vos, Van Duijvenvoorde et al. (2017). Bravo, Duarte et al. (2020). Cardona, Arango et al. (2017). Etehad, Yousefzadeh-Chabok et al. (2015). Hamido, Hamamoto et al. (2021). Lee, H. H., Cho et al. (2019). Kong, Hyun Kim et al. (2018). Momtaz, Kargar et al. (2018). Nishida (2015). Pourebrahim, Bafandeh-Zendeh et al. (2021). Prochowski, Gidlewski et al. (2018). Rapoport, Chee et al. (2021). Wei, Huang et al. (2020).
Negative binomial regression	Lee, D., Guldmann et al. (2019); Lee, S., Yoon et al. (2020); Palumbo, Pfeiffer et al. (2019); Park, Choi et al. (2021).
Binary/Multinomial logistic regression model	Adebisi, Ma et al. (2019); Alhomaidat, Abushattal et al. (2022); (Amin, 2020); Ayuso, Sánchez et al. (2020); Casado-Sanz, Guirao et al. (2019); Doi, Ishii et al. (2020); Doulabi and Hassan (2021); Gim (2022); Haule, Sando et al. (2019); Huseth-Zosel and Hammer (2018); Kim, D. (2019); Kim, Seunghoon, Lym et al. (2021); Kitali, Kidando et al. (2017); Lalika, Kitali et al. (2022); Lee, H. Y., Youk et al. (2021); Ma, Lu et al. (2018); Matsuyama, Kitamura et al. (2018); Noh, Kim et al. (2018); Sadeghi-Bazargani, Samadirad et al. (2018); Sagar, Stamatiadis et al. (2020); Se, Champahom et al. (2020); Wang, Y., Haque et al. (2017); Wen, Qu et al. (2021)
Mixed logit model	Adanu, Lidbe et al. (2021); Kim, Sungyop, Ulfarsson et al. (2019); Pan, Wu et al. (2022).
Machine learning model	Al Mamlook, Abdulhameed et al. (2020); Alhomaidat, Abushattal et al. (2022); Amin (2020); Amiri, Sadri et al. (2020); Chen, Lihui and Wang (2017); Das, Bibeka et al. (2019); Yuan, Z., Guo et al. (2022)

Among crash analysis studies of the elderly, statistical methods are still the most commonly used. Some studies have used basic statistical analysis to find differences between samples. For example, Prochowski, Gidlewski et al. (2018) compared multiple risk indicators in different age samples, including yearly average values of crash participants and rates of injury and death. Cardona, Arango et al. (2017) analysed the frequency distribution profile of the deceased, death rates per hundred thousand inhabitants, potential years of life lost, and excess mortality among those over 60. Hamido, Hamamoto et al. (2021) used the chi-squared test and Mann–Whitney U test to investigate the characteristics of truck driver safety in an ageing society.

Other studies used negative binomial regression and binomial or multinomial regression models to analyse the crash data. For instance, Lee, S., Yoon et al. (2020) developed a negative binomial model using the number of elderly pedestrian crashes in areas with different income levels as independent variables to explore the effect of the built environment on elderly pedestrian crashes. Park, Choi et al. (2021) modelled the expected number of daily traffic crashes in each municipality they studied to investigate the impact of heatwaves on traffic crashes by time of day and age of casualties. Studies modelling the frequency of crashes in a certain study area mostly use the negative binomial model. On the other hand, a binomial or multinomial logistic regression is widely used for categorical variables such as crash severity. Because reducing crash severity is an important aspect of traffic safety research, many previous studies have developed multinomial logistic regression models to assess the factors influencing crash severity in elderly people. Ayuso, Sánchez et al. (2020) developed three multinomial logistic regression models for the subgroups of those under 65 years, those between 65 and 75 years, and those over 75 years. Noh, Kim et al. (2018) built four multinomial logit models to consider the unconditional and interaction effect.

However, in the commonly used generalised linear models, the variable coefficients are assumed to be fixed; this ignores the effect of variable heterogeneity. Therefore, mixed-effects models have emerged to explore the heterogeneous effects of variables and variable interactions. For example, Kim, Sungyop, Ulfarsson et al. (2019) developed a random-effect logistic regression model to account for the effect of an unobserved variable. Pan, Wu et al. (2022) compared three mixed logit models to find the best-performing model and quantify the heterogeneity of the variables: the random parameters logit model, the random parameters logit model with heterogeneity in mean, and the random parameters logit model with heterogeneity in mean and variance.

With the emergence of big data and the development of artificial intelligence technology, machine learning has been widely used. Many scholars have begun to use artificial intelligence methods to predict the severity of crashes or to find their causal factors. Yuan, Z., Guo et al. (2022) used the XGB-Apriori algorithm to find the chain of rules for crashes of different severity. Amiri, Sadri et al. (2020) compared an artificial neural network with a hybrid (intelligent) genetic algorithm to validate their effectiveness in predicting crash severity. Al Mamlook, Abdulhameed et al. (2020) explored the impact of sample balance on prediction algorithms and the accuracy of five machine learning algorithms: Logistic Regression (LR), Decision Tree (DT), Light gradient-boosting machine (GBM), Random Forest, and Naive Bayesian (NB). Previous studies concluded that machine learning methods have higher prediction accuracy than other methods but a poorer interpretation of the data.

Although several methods have been used to analyse elderly-involved crash data, the dependent variable settings cannot be ignored. Dependent variables usually vary for different research purposes; they may comprise the number of pedestrian injuries (Lee, S., Yoon et al., 2020), the gender of elder drivers involved in traffic crashes, the probability of an occurrence of traumatic brain injury (TBI) in the elderly (Lee, H. Y., Youk et al., 2021), the proximity (close or far from home) of crash locations to pedestrian residences (Haule, Sando et al., 2019), as well as the severity of the crash (Al Mamlook, Abdulhameed et al., 2020; Amiri, Sadri et al., 2020; Ayuso, Sánchez et al., 2020; Casado-Sanz, Guirao et al., 2019; Das, Bibeka et al., 2019; Kim, Seunghoon, Lym et al., 2021; Noh and Yoon, 2017; Sadeghi-Bazargani, Samadirad et al., 2018; Wen, Qu et al., 2021; Yuan, Q., Zhang et al., 2022).)). Inconsistency in crash severity variables might create problems for comparing studies or generating common conclusions. For example, some scholars use a five-level classification of crash severity, while others use only two or three categories. This can have a significant impact on the analysis results.

The mixed logit model appears to be the most suitable for processing elderly crash data, as it is beneficial for discovering the risk-influencing factors of crash severity and is able to deal with the potential random effects of the factors at hand. If the crash sample size is large, the machine learning model, or a hybrid approach combining machine learning and the logit model, is also recommended; this would facilitate both the discovery of the effective utility of the factors and the quantification of their effects.

5. INFLUENCING FACTORS OF ELDERLY CRASHES

The traffic system is a massive, complex system consisting of humans, vehicles and road environments; problems arising from any one element may lead to a collision. Most studies investigate the influencing factors of crashes from five major aspects: human, vehicle, road, environment and macro socioeconomic factors. Some studies also evaluate crash attribute aspects.

Among the influencing factors, human-related factors include age, gender, driver age, area of injury, the physical condition of the driver, height, weight, annual working days, annual driving mileage, medication, status of frailty, cognitive impairment, systolic blood pressure, seat belt use and the purpose of travel. Vehicle-related factors include vehicle type, vehicle speed and age of vehicle. Road-related factors include road type, road alignment, vertical curve type, shoulder type, road surface condition, median type, number of lanes, control mode, speed limit and road length. Environmental factors include light conditions, day of the week (i.e. workweek or weekend), time of day (i.e. rush hour or off-peak), weather conditions, urban or suburban character, annual average daily traffic (AADT) and season. Socioeconomic factors include population density, elderly population ratio, transfer population ratio, floating population density, poverty rate, working population density, business density, apartment ratio, commercial area ratio, green area ratio, industrial area ratio, mixed land use characteristics, road density, bus stop density, subway station density, school zone density, intersection density, the built environment characteristics and land use of crash locations, pedestrian residence location, median household income, property value, and crash area population density. Crash-related factors include number of occupants, crash responsibility, type of crash, number of victims, and pedestrian and vehicle direction of travel.

The literature matrix of factors influencing traffic crashes involving elderly people is listed in *Table 3*. Due to sample limitations, it was not possible to analyse all possible influencing factors in the existing studies. The crash data obtained from the traffic management department usually includes crash attribute factors, personnel factors, vehicle factors and environmental factors. Data obtained from hospitals or emergency centres can include some additional factors (e.g. injury location, blood pressure). Furthermore, most of the data analysed in this literature review are dependent on police reports, which can be compromised by problems such as inconsistent reporting standards, misreporting and underreporting. Additionally, factors are not necessarily defined consistently across studies. For example, some define road type as road class (e.g. expressway, highway), while others define it in terms of proximate or non-proximate intersection.

Table 3. Literature matrix on factors influencing traffic crashes involving the elderly

Factors	Sub-factors	Reference
Crash	Responsibility	Amiri, Sadri et al. (2020); Ayuso, Sánchez et al. (2020); Lee, H. Y., Youk et al. (2021)
	Type	Ayuso, Sánchez et al. (2020); Etehad, Yousefzadeh-Chabok et al. (2015); Kim, Seunghoon, Lym et al. (2021); Lee, H. Y., Youk et al. (2021)

Factors	Sub-factors	Reference
Human	Occupants(number)	Ayuso, Sánchez et al. (2020); Doi, Ishii et al. (2020); Etehad, Yousefzadeh-Chabok et al. (2015); Huseth-Zosel and Hammer (2018); Kong, Hyun Kim et al. (2018); Matsuyama, Kitamura et al. (2018); Sadeghi-Bazargani, Samadirad et al. (2018)
	Age	Al Mamlook, Abdulhameed et al. (2020); Amiri, Sadri et al. (2020); Ayuso, Sánchez et al. (2020); Cardona, Arango et al. (2017); Casado-Sanz, Guirao et al. (2019); Doi, Ishii et al. (2020); Haule, Sando et al. (2019); Huseth-Zosel and Hammer (2018); Kim, Seunghoon, Lym et al. (2021); Kim, Sungyop, Ulfarsson et al. (2019); Matsuyama, Kitamura et al. (2018); Noh, Kim et al. (2018); Noh and Yoon (2017); Palumbo, Pfeiffer et al. (2019); Sagar, Stamatiadis et al. (2020) Wen, Qu et al. (2021)
	Gender	Al Mamlook, Abdulhameed et al. (2020); Amiri, Sadri et al. (2020); Ayuso, Sánchez et al. (2020); Cardona, Arango et al. (2017); Casado-Sanz, Guirao et al. (2019); Doi, Ishii et al. (2020); Haule, Sando et al. (2019); Huseth-Zosel and Hammer (2018); Kim, Seunghoon, Lym et al. (2021); Kim, Sungyop, Ulfarsson et al. (2019); Matsuyama, Kitamura et al. (2018); Noh, Kim et al. (2018); Noh and Yoon (2017); Palumbo, Pfeiffer et al. (2019); Sagar, Stamatiadis et al. (2020) Das, Bibeka et al. (2019); Kong, Hyun Kim et al. (2018); Lee, H. Y., Youk et al. (2021); Lee, J. and Gim (2020); Pan, Wu et al. (2022); Wen, Qu et al. (2021); Yuan, Z., Guo et al. (2022)
	Area of injury	Lee, H. Y., Youk et al. (2021); Lee, J. and Gim (2020)
Vehicle	Type	Ayuso, Sánchez et al. (2020); Casado-Sanz, Guirao et al. (2019); Das, Bibeka et al. (2019); Hamido, Hamamoto et al. (2021); Kim, Sungyop, Ulfarsson et al. (2019); Lee, H. Y., Youk et al. (2021); Noh, Kim et al. (2018); Noh and Yoon (2017); Pan, Wu et al. (2022); Sadeghi-Bazargani, Samadirad et al. (2018)
	Protection	Ayuso, Sánchez et al. (2020); Kong, Hyun Kim et al. (2018); Lee, H. Y., Youk et al. (2021); Wen, Qu et al. (2021); Yuan, Z., Guo et al. (2022)
	Speed	Yuan, Z., Guo et al. (2022)
Road	Road surface	Amin (2020); Amiri, Sadri et al. (2020); Casado-Sanz, Guirao et al. (2019); Kim, Seunghoon, Lym et al. (2021); Noh and Yoon (2017); Pan, Wu et al. (2022); Wen, Qu et al. (2021); Yuan, Z., Guo et al. (2022)
	Shoulder type	Kim, Seunghoon, Lym et al. (2021); Pan, Wu et al. (2022)
	Type	Amin (2020); Amiri, Sadri et al. (2020); Ayuso, Sánchez et al. (2020); Kim, D. (2019); Kim, Seunghoon, Lym et al. (2021); Noh and Yoon (2017); Yuan, Z., Guo et al. (2022)
	Alignment	Casado-Sanz, Guirao et al. (2019); Kim, Sungyop, Ulfarsson et al. (2019); Noh and Yoon (2017); Pan, Wu et al. (2022)
	Vertical curve type	Casado-Sanz, Guirao et al. (2019); Kim, Sungyop, Ulfarsson et al. (2019); Noh, Kim et

Factors	Sub-factors	Reference
		al. (2018); Noh and Yoon (2017); Pan, Wu et al. (2022)
Environment	Light conditions	Al Mamlook, Abdulhameed et al. (2020); Amin (2020); Amiri, Sadri et al. (2020); Ayuso, Sánchez et al. (2020); Das, Bibeka et al. (2019) Huseth-Zosel and Hammer (2018); Kim, Seunghoon, Lym et al. (2021); Kim, Sungyop, Ulfarsson et al. (2019); Pan, Wu et al. (2022); Wen, Qu et al. (2021); Yuan, Z., Guo et al. (2022)
	Weather	Amin (2020); Haule, Sando et al. (2019); Kim, Seunghoon, Lym et al. (2021); Kim, Sungyop, Ulfarsson et al. (2019); Pan, Wu et al. (2022); Wen, Qu et al. (2021); Yuan, Z., Guo et al. (2022)
	Built environment	Haule, Sando et al. (2019); Kim, D. (2019); Kim, Sungyop, Ulfarsson et al. (2019); Lee, J. and Gim (2020); Lee, S., Yoon et al. (2020); Pan, Wu et al. (2022); Wen, Qu et al. (2021)
Demographic	Total population	Lee, S., Yoon et al. (2020)
	Household income	Haule, Sando et al. (2019)
	Population density	Haule, Sando et al. (2019); Lee, J. and Gim (2020)

Summarising the current literature allows the following conclusions to be drawn. First, older drivers face a higher risk of fatal injury than younger drivers, due to the increased risk of crashes caused by impaired vision and longer reaction time in complex driving environments; older drivers are more likely than younger drivers to make mistakes in a crash. Second, in areas with high traffic volumes and facilities, there is an increased risk of crash severity involving older drivers. Third, factors related to the built environment significantly influence the severity of traffic injuries to older people.

To address the risk factors analysed here, scholars generally recommend the following measures to improve road safety for older travellers. Facilities such as street trees, parks and recreational lands can improve the safety of older pedestrians. Furthermore, improving street crossings and intersections are critical for the safety of older pedestrians. For older drivers, regular retraining and physical examinations should be organised. The risk of accidents for older drivers can be reduced by providing accessible routes, reliable and convenient public transportation and timely warnings of crash risks and changes in road geometry. Finally, implementing reliable driver assistance technology in cars (even self-driving cars) and encouraging social activities for active transportation are recommended safety measures.

6. CONCLUSIONS AND FUTURE RESEARCH

As populations inevitably age, ensuring the traffic safety of the elderly becomes increasingly important. The literature, although extensive, is difficult to compare given scattered research objectives and inconsistencies in the definition of variables. This study sought to find the conclusions, limitations, and development directions of this research by retrieving and reviewing crash analysis studies of the elderly from 2015 to the present. Accordingly, crash analysis methods and crash characteristics and crash-influencing factors among the elderly were reviewed.

Most current studies on the analysis of traffic crashes in the elderly are conducted in the United States and Korea. Most scholars use an age range beginning at 60 or 65 years old to define the elderly. Common research methods include statistical and machine learning methods. Human, vehicle, road, environmental, and socioeconomic factors influence the risk and severity of crashes among the elderly.

The following findings have been obtained:

There is no uniformity in the definition of older adults and the sample of older adults extracted for analysis. Heterogeneity might exist in elderly people of the same age, influenced by a variety of factors (e.g. different regions, different jobs, different household incomes). More research should be conducted to explore the homogeneity and heterogeneity of older populations.

The causes of crashes involving elderly pedestrians and those involving elderly drivers may be quite different. However, most of the current studies have studied these two groups together. Further research is needed for an in-depth analysis of the causal factors of different elderly traffic injury groups.

Moreover, the causes of traffic crashes for the elderly, when considering specific road objects and specific crash types, are not clear. Due to the limitation of sample size, most existing studies have investigated the causes of traffic crashes among the elderly in a comprehensive manner but have not paid attention to the causes under specific conditions (e.g. rear-end crashes, crashes at signalised intersections).

Ultimately, the heterogeneity of factors influencing traffic crashes in the elderly has not been fully revealed. Few existing studies have used advanced statistical models, such as the random parameters logit model with heterogeneity in mean and the random parameters logit model with heterogeneity in mean and variance, to study traffic crashes in older adults.

AUTHOR CONTRIBUTIONS

Conceptualization: Gu X; methodology: Lu X, Zhou YT; software: Jin X, Guo YJ; investigation: Gu X, Lu X, Jin X, Guo YJ, Zhou YT; resources: G.F.; data curation: Gu X; writing—original draft preparation: Gu X, Lu X, Jin X; writing—review and editing: Guo YJ, Zhou YT, Chen YY; supervision: Gu X, Chen YY. All authors have read and agreed to the published version of the manuscript.

ETHICS DECLARATION

The authors declare that they have no conflicts of interest regarding the publication of the paper.

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