도시계획학 석사학위논문

The Characteristics of Urban Elderly Drivers' Traffic Accidents

- Generalized Ordered Logit Model -

도시 고령 운전자의 교통사고 특성
- 일반화된 순서형 로짓 모형 적용 -

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이 지 원

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- Generalized Ordered Logit Model -

지도교수 김 태 형

이 논문을 도시계획학 석사학위논문으로 제출함

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서울대학교 대학원

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이 지 원

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2018년 12월

위 원 장 ______김 경 민______(인)

부위원장 ______최 재 성______(인)

위 원 ______김 태 형______(인)

Abstract

In the last several years, due to the rapid aging of the population, the number of traffic accidents caused by elderly drivers has dramatically increased. Previous studies have focused on investigating human factors (such as physical aging and psychological conditions) of elderly drivers. Furthermore, these studies also found that the impact of environmental factors on elderly drivers was more pronounced than on non-elderly drivers. Finally, several studies demonstrated that traffic accidents with elderly drivers were more likely to lead to severe injuries.

However, despite the differences between elderly and non-elderly drivers, relevant policies aimed at enhancing road safety have largely focused on improving road engineering. Therefore, in order to ensure the mobility of elderly drivers and establish a secure city, it is necessary to consider various factors that affect the driving and perform the research using the urban planning approach.

For these reasons, the present study aims to investigate the factors affecting the number and severity of traffic accidents by elderly drivers in Seoul. To this end, the study analyze the factors affecting the age-related traffic accidents by dividing the elderly groups into the young elderly drivers group (from 65 and 69 years old) and the middle- and old-elderly drivers group (above 69 years old). Also, to investigate the characteristics of accidents caused by elderly drivers, the study also used the non-elderly group for the sake of comparison. The research hypothesized that the characteristics traffic accidents vary across age groups; also

predicted that there would be differences in how the factors affecting drivers would impact each of the two elderly drivers groups. To formulate the hypotheses and interpret the results, it has first undertaken a thorough review of the literature on elderly drivers and the factors affecting them in urban environment.

In this study, since the dependent variables were discrete and distributed in an ordered form, the ordered logit model applied was used the first analytical model. The ordered logit model should satisfy the parallel assumption that the influence of the explanatory variable X does not change the value in any of the dependent variable categories, even though the dependent variable has an ordered form. Therefore, there is a limitation that the research results can be misinterpreted if the parallel assumption is not satisfied. Accordingly, the generalized ordered logit model, which relaxes the parallel assumption that the size of the regression coefficient is partially different from the dependent category, was also applied as the second model.

The results of applying the ordered logit model analysis showed that the null hypothesis of the parallel line assumption had to be rejected. Therefore, the present study developed the traffic accident characteristics model for accident severity using the generalized ordered logit model. The results of the analysis demonstrated that there were significant differences in the variables for each age group.

In particular, there was a significant difference between the elderly drivers groups and non-elderly drivers group with regard to accident severity. The same factors were found to have different magnitude and impact direction among the age groups. Among these variables, public transportation accessibility (i.e.

subway density and bus stop density) was found to have a positive impact on the occurrence of traffic accident severity in the three groups. In the non-elderly drivers group, the subway density increased the risk of injury severity, while it increased the risk of fatal accident in the young-elderly drivers group. In middle- and old-elderly drivers group, the bus stop density, rather than subway density, was a stronger risk factor that increased the number of fatal accidents. The use of public transportation was also found to increase the risk of exposure to traffic accidents. Frequent bus traffic and bus-only lane were found to have an adverse effect on the visibility of elderly drivers, which has led to an increase in accident severity.

The influence of aging among drivers on the number and severity of traffic accidents was also confirmed by the results of the present study. The risk of severe accidents of elderly drivers increased at the traffic islands which are usually installed at large intersections, thereby narrowing the road. Driving at nighttime, which is difficult in terms of visibility, was found to be another risk factor that increased the number of serious accidents in the young elderly drivers group and the number of fatal accidents in the middle- and old-elderly drivers group.

The impact of urban environmental factors on the number and severity of traffic accidents among elderly drivers, particularly in the middle- and old-elderly drivers group, was prominent. The factors that increased the number of traffic accidents, such as serious injury accidents or fatal accidents, in the middle- and old-elderly drivers group were household density, business density, and mixed land use. Those were mostly observed in the areas with a greater concentration of the population, and as well in the areas with a high traffic volume.

This result is in a striking contrast from the results in non-elderly drivers. In the latter group, the incidence of serious injury accidents decreased in the commercial areas with high traffic volumes for business and commercial facilities. Therefore, it appears that the urban environmental factors have a significant influence exclusively on elderly drivers from both groups.

In the injury accident and minor injury accident, the characteristics of the area affected the elderly driver's human factors, such as a decrease in cognitive reaction time and physical aging. The increase of the risk of accidents in areas with many detached houses or school zones density can be explained by the impact of the narrow width of the roads and frequent pedestrian traffic in those areas, as well as by the physical characteristics of children (such as low height) which imposes difficulties in terms of seeing children in blind spots. The higher risk of traffic accident occurrence in school zones suggests an urgent need of additional remedial action.

The results of the study are consistent with the results of previous studies that demonstrated an increase if the number and severity of traffic accidents among elderly drivers in the complex driving environments. However, as suggested by the results of the present study, such the complex driving environments include not only the road environments, such as the road extensions, intersections, and so forth, but also the spatial characteristics of accident locations.

The study also found that the factors affecting the accident severity among of elderly and non-elderly drivers groups were different. Furthermore, it also found that the factors affecting

accident severity and their magnitude differed between the two elderly groups as well. Finally the results of the analysis confirmed that urban environmental factors have a significant effect on traffic accident and its severity.

This research demonstrated the effect of various urban environment and regional factors on the number and severity of traffic accidents caused by elderly drivers. The results of present study emphasize that traffic safety and risk factors of traffic accidents are major planning factors that should be considered in urban planning. In order to ensure the mobility of elderly people and to effectively prevent traffic accidents, it is necessary to improve physical environment of multi-accident areas considering the spatial characteristics, the road environment, and the human factors. Furthermore, to develop various educational programs that would reflect the characteristics caused by elderly drivers and to improve social consciousness about the potential risks associated with elderly drivers.

Key words : elderly driver, accident, accident severity, injury severity, generalized ordered logit model
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I. Introduction

1. Research background and objectives

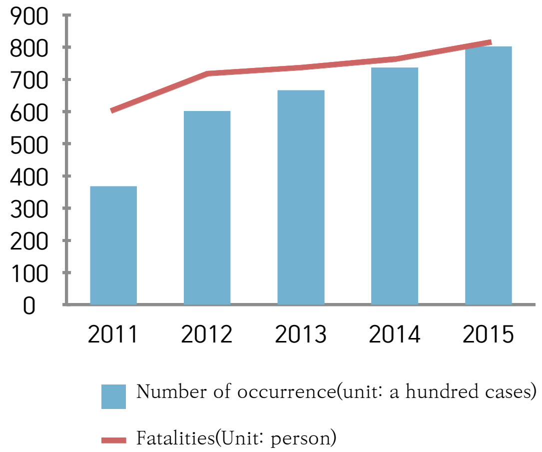
In 2007, the World Health Organization(WHO) announced that the global trends that will significantly affect the 21st century are aging and urbanization[1]. In 2007, the global urbanization reached more than 50%, so over half of the population lived in cities. According to recent estimates, by 2050, the global aging rate will amount to 22%, while the urbanization rate will increase to 66.4% (KOSIS, 2018). By 2027, South Korea will become a super-aged society[2], and the global urbanization rate is predicted to exceed 80%(U.S Census Bureau, 2015). Aging could be interpreted as a natural social phenomenon. However, it brings about many social problems for which the society is not adequately prepared yet. Traffic accidents by elderly drivers, which are among such social problems, have shown an increasing tendency in the last couple of years as shown in [Figure 1-1]. This issue has attracted considerable academic and policymakers' interest in industrial countries, including South Korea.

According to the 'Traffic accident status' from Korean ROAD Traffic Authority, from 2011 to 2015, the number of traffic accident fatalities by non-elderly drivers in South Korea decreased

1) The opening line of 'Global Age-Friendly Cities: A Guide' issued by World Health Organization in 2007

2) Elderly: The proportion of the population over 64 years old in the total population
· Aging Society: More than 7% of the population are elderly people
· Aged Society: More than 14% of the population are elderly people
· Super-aged Society: More than 20% of the population are elderly people

by 17.2% from 4,594 to 3,802 fatalities, respectively. By contrast, the number of traffic accident fatalities by elderly drivers increased by 34.7% from 605 deaths in 2011 to 815 deaths in 2015. Furthermore, traffic accidents among elderly drivers are more likely to lead to serious injuries than those committed by non-elderly drivers(Ferguson et al., 2002; Boufous et al., 2008). According to the number of traffic accident death per 10,000 driver license holders by age[see Table 1-1], the number of fatalities and traffic accidents grows with an increase of the driver's age; accordingly, this number is considerably higher in the elderly group.



Reconstitution of table 1 in KRIHS POLICY BRIEF no.586, KRIHS(2016)

[Figure 1-1] Traffic accidents by elderly drivers in South Korea(2011~2015)

[Table1-1] Traffic accident occurrence per 10,000 license holders by age

Age	Traffic accident per 10,000 license holder	Number of fatalities per 10,000 license holder
Under 20	274.373	4.380
20-24	50.632	0.987
25-29	65.291	1.252
30-34	58.904	1.213
35-39	53.332	0.893
40-44	58.626	1.060
45-49	71.003	1.312
50-54	86.817	1.601
55-59	94.304	1.914
60-64	99.425	2.153
65-69	100.524	2.782
70-74	104.259	3.542
75-79	99.502	5.024
More than 80	86.027	6.253

Source: TASS, Korea ROAD Traffic Authority

The increase in traffic accidents involving elderly drivers is criticized on the grounds that previous studies and policies have focused on the variables that are easy to acquire, such as road structure, vehicle technology, and accident data(vehicle type, violation of traffic regulations, etc.), while neglecting various factors including urban environment(Oh et al., 2015; Rhee, 2016; Jang et al., 2017). Accordingly, the implemented traffic accident prevention policies and related studies have mainly considered strengthening the physical environment, such as improvement of traffic facility safety(automated speed trap, installing signal), and road safety maintenance. However, despite remarkable improvement that resulted from the development of vehicle safety technologies, according to the 2014 OECD report entitled 'The comparison of traffic accidents in the OECD member countries in 2014', the number of traffic accidents per 10,000 vehicles in South Korea was 93.0 cases, which was the second highest among the member countries, and twice higher than the average of 52.5 cases in the member countries. This statistic shows that there is a limitation in the reduction of the number of traffic accidents when only the road engineering centered approach is applied. Traffic accidents are a result of an interaction of diverse factors, so even if two accidents occur under the same road conditions (e.g., number of lanes, speed limit, road type, etc.), the type of traffic accident and the degree of severity of these two accidents may differ. Therefore, in order to preemptively prevent the occurrence of traffic accidents and to introduce policies that can effectively cope with accidents afterward, it is necessary to consider various factors affecting traffic accidents and approach the issue from the perspective of urban planning.

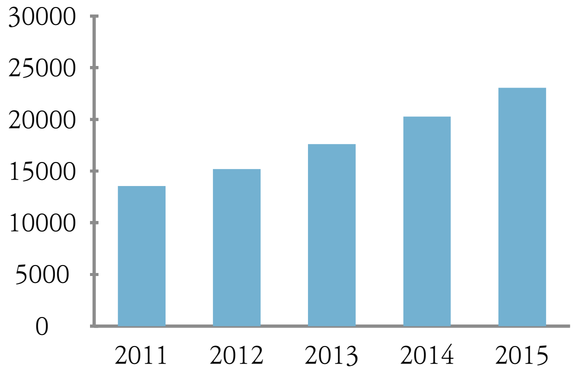
In this context, the present research focuses on the factors such as regional and spatial features, as well as elderly driver's human factors which were not sufficiently considered in previous research. The primary research goal of the study is to analyze the factors affecting traffic accidents by elderly drivers in Seoul by accident severity. Seeking to examine accident characteristics by age thoroughly, the present study divided the elderly drivers aged over 64 years old into the following two age groups: the young-elderly drivers (from 65 and 69 years old), and the middle- and old-elderly drivers (above 69 years old). The results of the present study may contribute to fundamental research for policy proposals to prevent traffic accidents among elderly drivers.

2. Research range and methodology

1) Research range and data

(1) Research range

The analysis area is the city of Seoul in South Korea. Traffic accidents by elderly drivers in Seoul show a clear upward trend in the last couple of years as shown in [Figure 1-2]. As Seoul has the highest population density by area(㎡) in the country, which is two times as population density of New York in 2010, and it also has various urban forms.



Source: TASS, Korea ROAD Traffic Authority

[Figure 1-2] Traffic accidents of elderly drivers in Seoul(2011~2015)

In this study, 424 administrative districts[3] (Traffic Analysis Zone)[4] of Seoul are set as spatial ranges, and the analysis data is

3) Administrative district is a unit established by the administrative convenience of residents.

4) Traffic Analysis Zone is the minimum unit of space used in traffic accident analysis.

based on the year of 2015. In the present study, it selected the traffic accidents cases which caused by elderly drivers, aged over 64. To facilitate the research purpose, it classified the subjects into two groups; young-elderly drivers group who aged over 64 under 70, and middle-and old-elderly drivers group who aged 70 years or older.

(2) Data

The traffic accident data, which used in the analysis were obtained from the Korean National Police Agency which has been collected from 25 boroughs in Seoul. The traffic accident data consisted of items as [Table 1-2]. The items of traffic accident data are recorded based on beopjeongdong[5] units. However, since the raw data of the input variables, which indicating the demographic and socioeconomic indicators, are collected by administrative units, it is necessary to convert the unit of traffic accident data into administrative districts. Since the traffic accident raw data of the Korean National Police Agency did not provide the coordinates of the traffic accident location, it converted to the administrative districts using the address recorded in the item of the place of accident occurrence.

[Table 1-2] Item list of traffic accident data

Items of traffic accident	
· Date and time of accident	· Injury from Traffic accident
· Accident location (Borough, Beopjeong-dong)	· Assailant·victim's human information(sex, age, injury)
· Road type	· Accident type
· Weather condition	· Violation of regulation

5) Beopjeong-dong is an administrative district unit designated by law

2) Research methodology and structure

The research method and structure to figure out the traffic accident characteristics of urban elderly drivers are as follows.

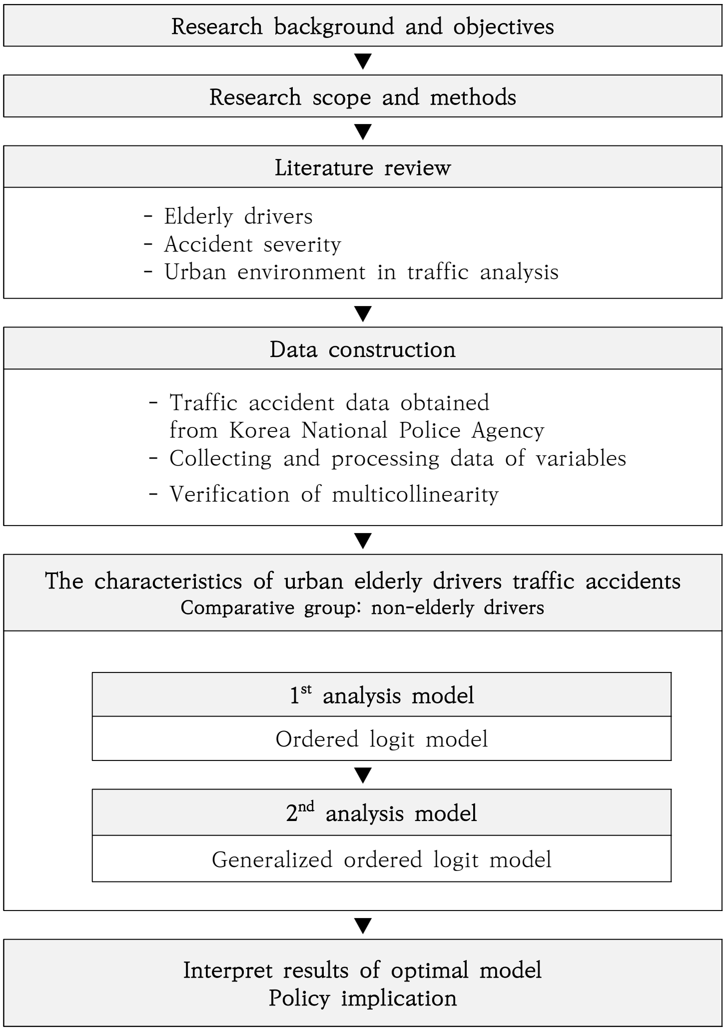
Firstly, to understand the characteristics of factors affecting the traffic accidents by the age of urban elderly drivers accurately, elderly driver groups are classified into young-elderly drivers group and middle- and old-elderly drivers group.

Secondly, the research conducted the literature review which related to the characteristics of the elderly drivers and the accident severity and set the candidate variables predicted to affect the accident occurrence by injury severity. The final input variables were selected considering the possibility of data acquisition and the concurrence of the research goal. From the data selection stage, the present study aimed to improve the effectiveness of the analysis results and ensure the differentiation of the research by considering the consistency between the result of analysis and the traffic safety policy.

Thirdly, some of the collected data sets were regenerated using GIS technique according to the analysis unit. The final input variables were chosen after the examination of multicollinearity.

Fourthly, the present study applied the ordered logit model and the generalized ordered logit model to examine the characteristics of elderly drivers' traffic accidents by severity. The study also investigated the accident severity of non-elderly drivers to compare the affecting factors and traffic accidents' features between elderly and non-elderly drivers.

Lastly, the results of the analysis are synthesized and interpreted concerning policy implications. This study may help to understand the characteristics of accidents by traffic accident severity of elderly drivers in Seoul and to find the consistency with policies.



[Figure 1-3] Research flow chart

II. Literature review

1. Elderly drivers

Previous studies and policies related to traffic accidents have mostly focused on road environmental factors, such as roads, geometry, and road facilities. Prior research on traffic accidents by elderly drivers has been carried out in the fields of traffic, medicine, and health. This body of work has predominantly considered the influence of physical aging and psychological factors on elderly drivers' traffic accidents.

The influence of human factors (e.g. physical aging, psychological state, drunk driving, etc.) on driving of elderly drivers is stronger than on that of drivers that are less advanced in terms of age. For instance, with regard to decreased vision, which is a typical aging phenomenon, the vision of the elderly drivers is by 20% or more lower than that of drivers aged 30-40 years old. The reduction of Useful Field of View (UFOV)[6]caused by decreased vision affects the process of traffic accidents. In this respect, according to Ball et al. (1993) and Huisingh et al. (2017), elderly drivers with reduced UFOV have six times higher likelihood of a traffic accident than non-elderly drivers. Furthermore, the hearing loss among the elderly and the weakening of the body's musculoskeletal system increase the risk of serious accidents, which makes it difficult to respond promptly

6) UFOV is rounded areas around the fixation point where information necessary for task execution is extracted. As the ranged of UFOV decreases, the detection and response of obstacles appearing in the side and rear are delayed..

when an elderly driver recognizes an attention object in a blind spot while driving or when an unexpected situation occurs (Oh et al., 2015; Lee et al., 2015).

However, the physical aging of elderly drivers can hardly be the primary cause of traffic accidents. Physical aging has a negative impact on the process of recognition and judgment, thereby increasing the time required for information processing and acts as a weakness for elderly drivers who must make right decisions within a limited time frame. Furthermore, according to Jang et al. (2017), with an increase of a driver's age, the difficulty of operating a steering wheel also increases due to the deterioration of a motor nerve. Moreover, with an increase of the cognitive response time, the risk of an accident caused by self-judgment rate increases as well. For example, at intersections and in making the left turn, which usually are characterized by the need to consider many factors during driving, the number of traffic accidents of elderly drivers is considerably higher. It is so because the time necessary to evaluate the situation under complex driving conditions becomes longer, and the pressure of the rear vehicle (using a horn or high beam) is generated; accordingly, an elderly driver who feels psychological pressure performs an unreasonable left turn, which frequently leads to accidents (Lee, 2006; Zhang et al., 2000).

Furthermore, the elderly drivers are markedly less sure of driving condition than that of non-elderly drivers (Lee, 2008), and they are more affected by environmental factors (traffic volume, vehicle speed, road type). In this respect, Lee et al. (2012) argued that aged drivers are more sensitive to environmental conditions and facilities during driving, which results in higher accident severity.

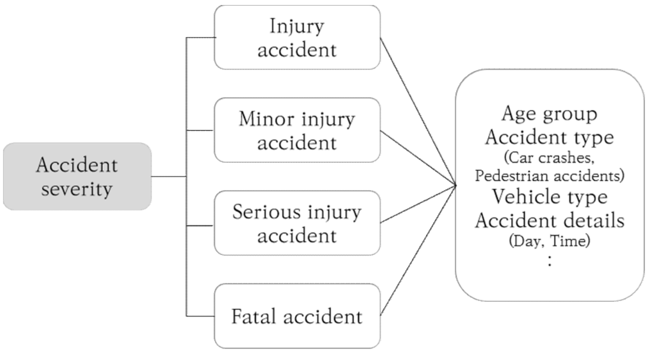
Finally, the evidence is available showing that there is a higher possibility of severe injuries among elderly drivers than among their younger counterparts (Lyman et al., 2002; Boufous et al., 2008). The risk of casualties in traffic accidents increases with an increase of the driver's age (Braver and Trempel, 2004). According to Choi(2017), there is a strong correlation between the risk of fatalities in traffic accidents and the degree of aging of elderly drivers; specifically, middle and old-elderly drivers are more likely to cause serious fatalities on the road as compared to young elderly drivers.

2. Accident severity

1) Input variables

The study on the accident severity has been considered the driver's age, accident types and vehicle types as dependent variables. Some previous studies considered differences of accidents severity affecting by driver ages or focused on particular age groups, such as elderly drivers or young drivers aged under 30. There were studies which examined the accident characteristics of pedestrian traffic accident severity(Park, 2014; Mohammed et al., 2013) and concentrated on accident severity of pedestrian-vehicle crashes(Chen and Shen, 2010). The analysis of traffic severity focused on accident types has performed, Kim and Park(2010) classified the type of accident vehicle into eight categories and proved that there were differences in factors affecting accident severity.

The input variables of accident severity studies were consisted of environmental factors (seasons, weather condition), accident types (cars crashes, pedestrian-vehicle accidents, and single vehicle crash), occurrence time (day, time), road environmental factors (road types, the width of the road, road lanes) and most of them were illustrated in police reports of accidents or mainly reflected road environment. Lastly, land use types, employment density, and the regional characteristics (Urban area or Rural area) were considered to reflect urban environment in the previous studies.



[Figure 2-1] Classification of traffic accident (Y)

[Table 2-1] Dependent variable types in related studies

1st classification	2nd classification	Related studies
Accident severity		Park et al.(2013), Abel-Aty(2003),Hadayeghi et al(2010)
Accident type	Accident severity	Quddus(2008), Wang et al.(2009)
Age		Zhang et al(1999), Park(2014), Choi et al.(2009), Lee et al.(2015)
Vehicle type		Kim and Park(2010), Chen and Shen(2016)
Objective: Pedestrian, cycle		Park(2014), Lascala et al(2000)

2) Affecting factors in accident severity

Among the demographic variables, driver age is an important factor predicting the rate of accidents. Overall, the highest accident rate is observed in males aged 10-20 years old, i.e. inexperienced drivers with inadequate driving skills (Park, 2014; Choi, 2009). The pedestrian-vehicle crash is the most severe type of accidents (Park, 2014); car crashes among elderly drivers have increased the possibility of serious accidents (Lee et al., 2008). Furthermore, several studies have reported that traffic accident severity is higher on weekdays rather than weekends (Bae et al., 2013); nighttime or bad weather conditions are also risk factors that increase accident severity (Park, 2014).

With regard to road factors, the number of road lanes and width of the road have been shown to increase the risk of traffic accidents with serious injuries (Park et al., 2013; Kim and Park, 2010); another relevant factor associated with higher accident severity is an intersection (Zhang et al., 2000; Boufous et al., 2008). Furthermore, several studies have demonstrated that speed limits positively affect accident severity and that lower speed limits reduce bicycle-vehicle accident severity (Siddiqui et al., 2012; Chen and Shen, 2016). Finally, as suggested by Noland (2013) and Noland and Quddus (2004), the road geometrical structure has a positive effect on the number of fatal accidents.

Among the indicators pertinent to the urban environment, mixed land use is a risk factor for accident severity (Boufous et al., 2008; Chen and Shen, 2016). Furthermore, Chen and Shen (2016) argued that employee density increases the severity of car-bicycle accidents. Likewise, bus stops increase the risk of fatal injuries as well (Kim and Park, 2010). Finally, in a study that analyzed the difference between urban and rural areas, Abel-Aty (2003) found that severe accidents in rural areas were caused by higher speed of vehicles enabled by lower traffic volumes on rural roads.

[Table 2-2] Precedent study on traffic accident severity

Author	Analysis model	Dependent variable	Explanatory variables			
			Traffic accident feature	Driver info.	Road environment	Urban environment
Zhang et al(1999)	Logistic regression model	Driver age	●	●	●	
Park(2014)	Ordered logit model	Pedestrian		●	●	
Park et al.(2013)	Ordered logit model	Accident severity	●	●	●	
Abel-Aty(2003)	Ordered Logit model	Accident severity		●	●	
Kim and Park (2010)	Possion, Negative binominal model	Vehicle type		●	●	
Bae et al.(2013)	SEM	Accident time		●	●	
Lee et al.(2008)	Ordered logit model	Elderly and non-elderly driver	●	●	●	
Boufous et al.(2008)	Multiple linear regression	Elderly driver		●	●	●
Mohamed et al.(2013)	Ordered Probit regression model, General logistic regression, cluster-based logistic regression analysis	Pedestrian-vehicle accident	●	●	●	●
Quddus(2008)	Possion, NB regression model, Spatial model, Bayesian hierarchical model	Vehicle type		●	●	
Chen(2015)	Generalized linear mixed model	Bicycle accidents	●	●	●	●

- Traffic accident feature: Accident type, vehicle type, time, weather condition etc.
- Driver information: Sex, age, drunk driving or not
- Road environment: Road type, road condition, average speed, road facilities etc.
- Urban environment: Average age of an analysis unit, employee density, land use types etc.

3. Urban Environment and Traffic

Urban environment has been used in many fields to examine various social phenomena in urban areas. Urban environment and traffic are interrelated, as urban environment determines an individual's traffic behavior and exerts a significant impact on traffic accidents. Since the late 1990s, urban design theories, such as new urbanism and transit-oriented development, have been widely used in traffic research. Specifically, the compact city has been used in research on traffic behavior and pedestrian accidents, which applied the concept of the theory that promoting the use of public transportation and reducing car use through high-density development and job-housing proximity.

Cervero and Kockelman(1997) analyzed the factors that constitute the compact city, such as mixed land use and pedestrian-friendly design by new urbanists and other scholars, and suggested the following three factors relevant for urban environment (the so-called 3D): Density, Diversity, and Design [see Table 2-3]. The concept of 3D has been revised to identify the travel behavior; however, this concept has also been used to explain the impact of urban environment on traffic accidents.

[Table 2-3] Built environment variables by Cervero and Kockelman(1999)

3D	Variables
Density	• Population density • Employment density • Accessibility to jobs
Diversity	• Dissimilarity index • Mixed land use Entropy • Land uses(Residential, commercial, office, industrial, institutional, parks and recreations) • Activity center mixture • Commercial intensities
Design	• Streets: 1)Pattern, 2)proportion of intersections, 3)per developed acre rates of freeway miles, over-pass, etc. • Pedestrian and cycling provisions: 1)proportion of blocks with sidewalks, planting strips, 2)proportion of intersections, 3) averages of block length, side walk width etc. • Site design: Proportion of commercial-retail and service parcels with: off-street parking; off-street parking between the store and curb etc.

Reconstitution of table 3 in Cervero and Kockelmand(1999)

First, density, which refers to population density and employment density, is a predictive value that can be used as the proxy for many difficult-to-measure variables that more directly affect travel behavior (Steiner, 1994; Ewing, 1994; quoted in Cervero and Kockelaman, 1997). Density is a key indicator that affects traffic accident occurrence. For instance, LaScala et al.(2000) and Hadeyegi et al.(2003) argued that a high population density increases traffic volume. The increase in traffic volume raises the risk of a conflict between vehicles and increases the incidence of traffic accidents. Household density also leads to an increase of traffic volume and, consequently, negatively impact the number of traffic accidents as well (Wang et al., 2009). In this respect, Noland and Quddus(2004) found that drivers tend to drive more carelessly in lower density areas, which could lead to fatal injuries in pedestrian-vehicle accidents. On the other hand, Rhee (2016) argued that traffic jams caused by the increase in traffic volume reduce the speed of driving, reducing severity of traffic accidents.

[Table 2-4] Density variable impact on the previous studies

Variable	Impact on traffic accident	Related literature
Population density	+	Hadeyeghi el al.(2003), LaScala et al.(2000), Park(2014)
	+:pedestrian-vehicle accident	Noland and Quddus(2004)
	-	Rhee(2016)
Household density	+	Wang et al(2009)
Employment density	+	Quddus(2008)

+: increase, -: decrease

Second, diversity refers to urban land use, mixed land use, and commercial facilities. Previous studies used proportion of land use types and mixed land use entropy. The land use is a factor indicating the essential feature of the traffic accident area. Since the characteristics of the land use influence various activities in the urban area, the impact on traffic accidents by the type of land use can vary. Land use diversity can be expressed as the land use balance and the land use mix (Gim and Ko, 2016; Rlee, 2016). The land use balance is an entropy index which adopts the Shannon entropy concept revised by Shannon(1989). If the entropy value is close to 1, it means the land use types are well-balanced; alternatively, if the value is close to 0, single land use type predominates in that area. A related measure, the Herfindahl index, has its roots in economic analysis and is defined as a concentration measure. The Herfindahl index is merely the sum of squares of the proportion of different land use types (as citied in Manaugh and Kreider, 2013). The land use mix is a measure of dissimilarity between land uses. Mixed land use factors have different effects on traffic accidents. Chen(2015) and Rhee(2016) showed that the more complex the land use, the more traffic accidents occurred.

However, Park(2014) demonstrated that the number of pedestrian-vehicle accidents decreased in residential areas and mixed land use areas. Specifically, Park(2014) argued that, in order to reduce traffic accidents, an in-depth urban design approach that would consider land use and urban environment is needed. In this respect, factors related to commercial facilities were also reported to an increase in the number of traffic accidents. For instance, Park and Lee(2013) analyzed the effect of street environment characteristics on the number of pedestrian-vehicle accidents using a spatial statistical model. Pedestrian traffic accidents were more likely to occur in areas of concentration of commercial facilities. In such areas, the risk of pedestrian traffic accidents increased due to the high traffic population and high traffic volume.

[Table 2-5] Diversity variables impact on the previous studies

Variable	Impact on traffic accident	Related literature
Mixed land use (Entropy)	+	Rhee(2016)
	+: Pedestrian-vehicle crashes	Chen(2015)
	-	Park(2014)
Residential area	-: Pedestrian-vehicle crashes	Park(2014)
Commercial intensities	+: Pedestrian-vehicle crashes	Park and Lee(2013)

+: increase, -: decrease

The third component of 3D—design—refers to the actual environment of the target area and includes road characteristics, such as parking lots in commercial facilities and sidewalks, which may affect traffic behavior and the number of accidents. Specifically, road factors and road facilities are the variables that have been frequently used in traffic accident analysis. Road area, road extension, and road rate were found to increase the number of traffic accidents (Zegger et al., 2001; Choi et al., 2009; Wang et al., 2013; Rhee, 2016). With regard to road area, the impact of traffic accident severity on accident occurrence area was found to vary according to urbanization rate. Specifically, Abel-Aty (2003) found that serious injury accidents are more frequent in rural areas than in urban areas. In non-urban areas, traffic inflow is small, and traffic volume is low due to traffic congestion and speed limitations. Therefore, there is a higher risk of severe accidents in non-urban areas where the driving speed is relatively higher than in urban areas. Furthermore, intersections with high traffic volume and a complex driving environment increase the risk of a traffic accident (Wang et al., 2013; Abel-Aty, 2003;

Cambell et al., 2004). Of note, Zegeer et al. (2001) argued that intersections in urban areas characterized by a high traffic volume are relatively less likely to cause traffic accidents than intersections in suburban areas.

[Table 2-6] Design variables impact on the previous studies

Variable	Impact on traffic accident	Related literature
Road ratio, Road extension, Road area	+	Bae et al.(2013), Rlee(2016), Zegger et al.(2001), Wang et al.(2013), Abel-Aty(2003)
Intersection	+	Wang et al.(2013), Abel-Aty(2003), Campbell(2004), Zegger et al.(2001)

+: increase, -: decrease

4. Summary and Implications

Previous research on elderly drivers—with the focus on human factors such as physical aging and psychological changes in elderly drivers—has been conducted in the fields of medicine, psychology, and traffic. Most previous studies suggest that elderly drivers' decline in the cognitive response time due to aging makes it difficult for such drivers to respond promptly, thereby causing severe accidents (Oh et al., 2015; Lee et al., 2015). Furthermore, with an increase in the age of elderly drivers, the risk of traffic accident casualties increases as well (Braver and Trempel, 2004; Choi, 2018). However, previous research has also demonstrated that considering only the demographic and socioeconomic characteristics and urban environmental factors are insufficient. Traffic accidents are caused by complex interactions of various factors in the driving environment; accordingly, accident severity may vary even if accidents occur under the same conditions. Also, in complex driving environments and the event of a high traffic volume, elderly drivers are more likely to cause more serious traffic accidents than non-elderly drivers (Lee, 2006; Zhang et al., 2000). Therefore, it is necessary to thoroughly analyze the factors affecting the number and severity of traffic accidents by age groups. Urban environment has been mainly used in travel behavior studies using urban design theory such as Compact City, New Urbanism, and so forth. Cervero and Kockelman(1997) proposed the concept of 3D that encompasses the parameters of density, diversity, and design and used this triad in the traffic accident analysis. In previous researches, the studies that focused on pedestrians have mainly employed urban environment factors. Although the urban environment factor has a significant influence on traffic accidents, studies on traffic accidents have focused on road factors. Therefore, in the traffic accident analysis, it is necessary to consider various components of an actual city.

The implications of the literature review undertaken in this section are follows

First, in order to investigate the factors affecting accident severity of elderly drivers, elderly drivers should be subdivided into different groups by age, and a comparative analysis of the performance of these groups should be conducted.

Second, it is necessary to identify various variables that are predicted to affect traffic accident severity. In particular, it is necessary to analyze the variables that can represent the urban environment, rather than the road environment variables which have mainly been used in previous research.

The features that differentiate the present study from previous research are as follows:

- In the present study, along with the variables that were predicted, in previous studies, to have a significant impact on traffic accidents, the present study also focused on the variables that were selected considering the spatial characteristics of Seoul.

- To analyze the characteristics of elderly drivers by accident severity, the study classified the elderly drivers were classified into the following two groups: the young-elderly drivers group (from 65 and 69 years old) and the middle- and old-elderly drivers (above 69 years old). As the control group, the study also included in the analysis the non-elderly drivers group (drivers aged between 30 and 64 years old).

III. Methods

1. Research Hypotheses

The causes of traffic accident can be classified into the vehicle factor, the road environmental factor, and the human factor. According to the 「AASHTO Highway Safety Manual (2010)」, among the three traffic accident factors, the accident caused by human factor took 57% of the total number of traffic accidents. If adding vehicle factors and road environmental factor to human factor, the human factor related to 97% of the total number of traffic accident. Elderly drivers suffer from declining recognition response due to physical aging and are thus more likely to be affected by facilities and the surrounding environment while driving as compared to non-elderly drivers (Lee et al., 2012).

Even if a traffic accident occurs in the same environmental condition, the factors affecting the driving and the injury severity may vary depending on the characteristics of an accident perpetrator. Therefore, in the present study, non-elderly drivers were used as the control group. The following two hypotheses were formulated:

- Hypothesis 1: Factors affecting the severity of traffic accidents may differ between elderly drivers and non-elderly drivers.

- Hypothesis 2: Factors which affect traffic accidents by injury severity may differ between young elderly drivers group and middle- and old-elderly drivers group.

[Table 3-1] Three factors of traffic accident

<table>
<tr><th>Factors</th><th colspan="2">Features</th></tr>
<tr><td>Vehicle factor</td><td>Physical characteristics of vehicle</td><td>Brake system, lightening, steers, etc.</td></tr>
<tr><td rowspan="4">Environmental factor</td><td>Geometry</td><td>Road type, width of lane, etc.</td></tr>
<tr><td>Driving environment</td><td>Traffic volume</td></tr>
<tr><td>Built environment</td><td>Land use type</td></tr>
<tr><td>Others</td><td>Signal, road surface, regulations, weather conditions, etc.</td></tr>
<tr><td rowspan="3">Human factor</td><td>Mental and physical characteristics</td><td>-</td></tr>
<tr><td>Purpose of driving</td><td>-</td></tr>
<tr><td>Others</td><td>Drunk driving, drug, etc.</td></tr>
</table>

Source: IRTAD(2017), 「Road Safety Annual Report 2017」, OECD ITF.

2. Methodology

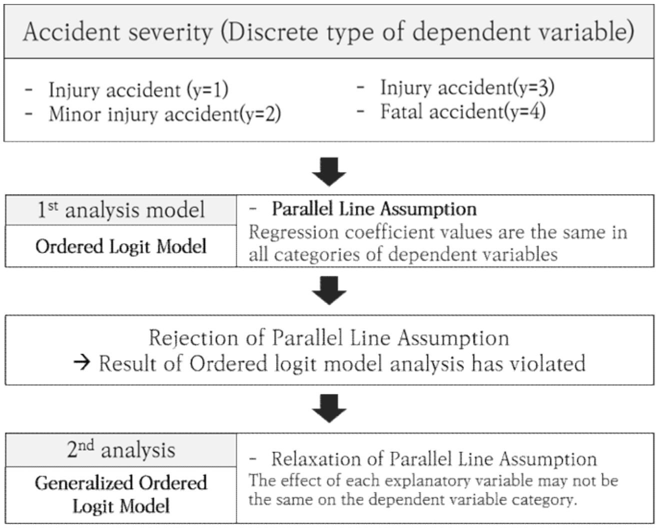
The current study used the ordered logit model and the generalized ordered model to examine the factors affecting the severity of traffic accidents by urban elderly drivers. In the traffic accident data obtained from the Korean national police agency, the accident severity classified into following four types; fatal accident, serious injury accident, minor injury accident, and injury accident.

The ordered logit model is suitable when the dependent variable is discrete, and distribution is in an ordered form. In the case of dependent variables (y = 0, 1) without order, it is possible to analyze through a probit model or a logit model. However, when the dependent variable is not the binomial (y=0,1), has more categories (y=0,1,2 or more), and ordered, general probit and logit models can generate mistakes (Choi et al., 2009). If the dependent variable is an ordinal type, performing general linear regression analysis is difficult; it is also difficult to interpret the relationship within the data because each category is an ordinal scale with different values. The ordered logit model has an order between each category of dependent variables and assigns a sequential score to explain the unequal distance between categories. Therefore, it is valuable to examine the influence of each explanatory variable on the types of the dependent variable.

On the other hand, the ordered logit model has a parallel line assumption that the influence of the explanatory variable x does not change in the category of any dependent variable, even though the dependent variable includes the ordered term. However, unobserved heterogeneity among the observations corresponding to each category of the dependent variable could exist. Therefore, the limitation is that it is difficult to obtain an estimator that reflects heterogeneity within a group by estimating a single regression coefficient (Williams, 2006; Savolainen et al., 2011; Lee and Kim, 2015).

Therefore, an ordered logit model should be applied through a null hypothesis test that the number of descriptive numbers for each category is the same for the magnitude of their influence on the dependent variables. If the hypothesis has to be rejected, the generalized ordered logit model can be applied to relax the assumption that the value of the regression coefficient may be partially different depending on the category.

Since Maddala (1983) and Terza (1985) introduced the concept of the generalized ordered logit model, it has been widely applied in different studies, including those focused on the severity of traffic crashes (Savolainen et al., 2011) or the analysis of determinants by health status (Lee and Kim, 2015). The generalized ordered logit model is less convenient than the ordered logit model, so there are not many studies it was applied. However, it is suitable to determine the influence of specific explanatory variables by category of dependent variables. In particular, the generalized ordered logit model has advantages in deriving policy implications for interested groups (Williams et al., 2005). The design of the present study is shown in [Figure 3-1].



[Figure 3-1] Research methodology framework

3. Analysis variables

1) Dependent variable

In the present study, accident severity was the dependent variable. In the traffic accident data of the Korean national police agency, the level of a traffic accident severity is classified according to the losses of life in a traffic accident.

According to the definition of traffic accidents[7], 'Fatal accident' means that there is more than one death; 'serious injury accident' means that there is no deceased person, and more than one person is seriously injured. Finally, 'minor injury accident' has one or more minor injured persons, and 'injury accident' includes only one or more injured persons[see table 3-2].

[Table 3-2] Accident by injury severity

Injury severity	Definition
Fatal	Death within 30 days of a traffic accident
Serious injured	Injured in a traffic accident requiring treatment for 3 weeks and above
Minor injured	Injured in a traffic accident requiring treatment for 5 days and under 3 weeks
injured	Injured in a traffic accident requiring treatment for under 5 days

Source: 'Traffic accident statistics report'(Korean National Police Agency, 2015), KoROAD

In the accident data from the Korean national police agency, according to the provisions of Article 2 of the 「Road Traffic Act」, a vehicle refers to an automobile, a construction machine, a motorcycle, a bicycle, a person, livestock, or other vehicles. The present study focused on the number of traffic accidents caused by passenger cars, vans, prime movers, and two-wheelers.

The research classified the subjects into three groups — the

7) Refer to 'Traffic accident statistics report'(Korean National Police Agency, 2015), KoROAD webpage(www.koroad.or.kr)

elderly driver group was subdivided into the young elderly drivers group (aged 65 to 69 years old), and middle- and old-elderly drivers group (aged 70 and over)[8][see table 3-2]. The third group was non-elderly drivers aged over 29 and under 65 years of age. The number of traffic accidents and traffic accident fatalities per hour in the group aged from 10s to 20s was reported to be 2.6 times higher than in other age groups (Hankyoreh, 2015.10.12). Young drivers are more likely less experienced in driving as compared to older drivers. Therefore, the research excluded the drivers in their 10-20s, as this group can have less stable driving characteristics compared to drivers from other age groups.

[Table 3-3] Traffic accident occurrence in Seoul(2015)

Division		Accident severity by injury severity				Group division
Age group		Injury accident	Minor injury accident	Serious injury accident	Fatal accident	
Under 20	876	182	424	253	17	
20-30	2505	305	1419	753	28	
30-40	3538	294	2099	1111	34	Non-elderly drivers group
40-50	4642	357	2801	1451	33	
50-60	6849	459	4249	2096	45	
60-65	3059	189	1907	939	24	
65-70	1956	107	1164	657	28	Young-elderly drivers group
70-80	1399	107	827	447	18	Middle- and Old-elderly drivers group
80-90	62	7	34	20	1	
90 and above	2	1	1	0	0	
Total	24888	2007	14924	7727	238	

Source: Traffic accident analysis system, KoROAD

8) Elderly can be divided as the three groups: Young-eldelry(aged 65-70), Middle-elderly(aged 70-74), Old-elderly(Above 74) Choi(2018) and Oh et al.(2016) divided elderly drivers as those of three groups, and the results shows that the older age group has more the risk of severe accident and the characteristics of traffic accidents showed a significant difference.

2) Variables selection

Concerning the literature related to traffic accidents and urban environment and the characteristics of Seoul city, the study chose the factors that are predicted to affect the traffic accidents committed by urban elderly drivers. The variables, which describe demographic and socioeconomic indicators, urban environmental indicators, and accident feature were selected as follows.

(1) Demographic and socioeconomic indicator

Urbanization not only reduces the speed of travel, but also increases the population at risk. The traffic volume in the target area is affected by the resident population. Population density and household density, which represent the population index of the region, increase traffic volume and traffic accidents in the area (Park, 2014; LaScala et al., 2000; Hadeyeghi et al., 2003). However, in an area with a low population density, careless driving can also lead to fatal injuries (Noland and Quddus, 2004), and the possibility of traffic accidents may decrease due to the traffic congestion (Rhee, 2016).

Depending on the age of the residents, the impact on traffic accidents may vary. The probability of a traffic accident decreases when the proportion of people aged 65 years old or older increases (Quddus, 2008; Wang et al., 2013). It appears that, compared to other age groups, elderly people have lower mobility, which also increases the risk of dangerous driving behavior. Furthermore, the population aged under 20 years old has a significant impact on the number of traffic accidents. In previous studies, the proportion of the population aged under 20 years old was found to be a factor that reduces traffic accidents (Lascala et al., 2000; Aguero-Valverde, 2013). In Korea, a driver's license[9] can be obtained from 18 years old, which reduces the possibility of exposure to a traffic accident by a driver who is under 20 years old.

According to the KOSIS 'Current status of driving license holders', the total number of driver license holders in Korea was 30,293,621 in 2015, of which 59% were males. Of note, more than 70% of traffic accidents are committed by males. Therefore, the present study investigates the effect of the male population on the number of accidents.

The city of Seoul has the highest density of population by area in the nation[10]. Although in recent years, population outflow[11] increased in Gyeonggi-do due to a rise in housing costs, the number of people who commutes to Seoul increased to 1,277,000 which is 26,000 higher than five years ago (Population and Housing Census, 2015). Therefore the present study considered the population that was not counted as the resident population of Seoul, but includes commuters who but work in the administrative district (employee density, business density) and the ratio of transferred population.

The density of employee and business density in the target area

9) Class 1 ordinary and class 2 -ordinary and class 2-small cars can be acquired from 18 years of age and above. In the case of class 1 and class 1 special vehicles, only an class 1- or 2-ordinary license holder who had acquired an year ago and above can be acquired(Source: The easy legal information service(easylaw.go.kr))

10) Seoul is an area of 1049㎢, and 17.5million inhabitants(as of 2016) in which is two times as the population of New York.

11) Based on the actual place of residence, the outflow between 2010 and 2015 shows that Seoul has the largest number of outflowed people(5.7million people), while Gyeonggi Province has the highest net inflow with 3.4million.

represent the living population in the weekly time zones and can be regarded as an index closely related to the traffic volume in the region. Employee density increases the likelihood of high accident severity and traffic accidents (Quddus, 2008; Noland and Quddus, 2004).

The poverty rate is mainly expressed by the income quintile or the ratio of basic living recipients. In the present study, the ratio of basic livelihood recipients in the administrative district was used as an explanatory variable. If the amount of income drops below 30% of the median income and does not meet the minimum cost of living standards[12], Basic livelihood recipients receive benefits such as livelihood, medical care, housing, and education benefits. Previous research demonstrated that the poverty rate, similarly to the unemployment rate, increases the risk of traffic accidents (Aguero-Valverde and Jovanis, 2006; Rhee, 2016).

12) The amount of recognized income is less than 30% of median income, and the amount of income according to household member is as follows.
- Single-member household: 501,632 won
- Two-member household: 804,129 won
- Three-member household: 1,105,761 won
- Four-member household: 1,355,761 won
Source: Bokjiro(www.bokjiro.go.kr)

[Table 3-4] Demographic and socioeconomic variables

Variable	Unit of a variable
Population density	Residents(unit: thousand)/area(㎢)
Household density	Households(unit: thousand)/ area(㎢)
Over aged 64 ratio	Over aged 64 population/ population
Under aged 20 ratio	Under aged 20 population/population
Male population ratio	Male population/ population
Transfer population ratio	Transfer population/population
Basic livelihood recipients ratio	Basic livelihood recipients/ population
Employee density	Number of employee(unit: thousand person)/ area(㎢)
Business density	Number of business(unit: thousand)/ area(㎢)

- Area: area of each administrative district
- Population: population of each administrative district

(2) Urban environmental indicator

School density and university density are expressed by dividing the number of school facilities (1,000 places) in the target area (㎢). School density includes elementary, middle, and high schools. It is predicted that traffic accidents will lead to serious traffic accidents, since children are likely to behave unexpectedly due to the lack of awareness of traffic safety. Furthermore, university density causes traffic volume; since students on campus use taxis, motorcycles, bicycles, and other means of transportation, the number of collisions between vehicles and pedestrian accidents typically increases. According to the Ministry of Education's '2011-2015 National Traffic and Accidents at National University', 483 traffic accidents occurred on campus. Despite frequent traffic accidents on the university territory, the campus roads are not covered by the 'Road Traffic Act' and are classified as off-road areas, which complicates accident prevention. Therefore, a high university density is related to a higher risk of injury severity.

Of the housing types in Seoul, apartments account for the largest percentage. In order to suppress traffic accidents in the construction of the apartment complexes, traffic accidents can be reduced, because the surrounding transportation environment can also be improved. However, it can equally be a factor that can increase injury severity due to the dense population and heavy traffic volume after high-density apartments are built. On the other hand, detached house includes multi-family housing. It is mainly located on narrow roads in a residential area and will have a significant impact on traffic accidents due to its high population density.

[Table 3-5] Supply of housing by housing types in Seoul(2015)

Proportion of housing type (%)				
Detached houses	Apartment	Town-house	Multi-family housing	House in non-residental buildings
32.90%	45.10%	3.20%	18%	0.80%

Land use is an essential variable in urban design and represents the risk characterization of the area. It is mainly used for traffic behavior analysis in traffic research. However, due to the differences in traffic volume, the purpose of travel, and the age of main users depending on the type of land use, it is likely to have a significant impact on traffic accidents and injury severity. For example, traffic accidents may increase in those areas where land use is mixed (Chen, 2015; Rhee, 2016). However, as land use becomes more complex, pedestrian-vehicle accidents can be decreased (Park, 2014). Seoul has dense and complex land use patterns. In order to investigate the effect of mixed land use on injury severity involving elderly drivers, the current study adopted the equation of Cervero and Kockelman(1997), which is calculated by applying Shannon's entropy concept in the land use balance. In the equation, p_j represents the occupied area ratio of the land use type I. J is the number of land use types. In this study, it included four land use types: residential, commercial, industrial, and green areas.

$$\text{Mixed land use} = -\sum_{i}^{n} \frac{p_j \ln(p_j)}{\ln(J)} \quad \text{[Equation 2-1]}$$

According to the Article 12 (Designation and Management of Child Protection Areas) of the 「Road Traffic Act」, a school zone is designated as a protected area, including mainly roads around facilities for children under 13 years old, such as kindergartens or elementary schools. To ensure children's safety, the traffic safety facilities and the road furniture are installed, and the drivers tend to drive slowly in a school zone to avoid accidents.

Due to its timeliness and convenience, public transport in the city is a means of transportation for many urban residents. Public transport facilities, such as bus stops and subway stations, may positively affect road safety and reduce the number of accidents by restricting the use of vehicles as a measure of service convenience (Rhee, 2016). However, the location of public transport stops can be close to intersections and crosswalks, which may increase the number of pedestrian-vehicle traffic accidents (Park, 2014). Therefore, the bus stops and subway stations were applied to investigate the effect of public transportation access to traffic accidents.

Road variables (road rate, road extension, road area, etc.) are frequently used as indicators of the urban environment. Among them, the road extension refers to the total road length of the study area, which has a significant effect on the number of traffic accidents. With an increase of the road capacity in urban areas, the traffic may increase, and the contact between vehicles may become frequent. Intersections are more traffic-intensive and complex, which increases the number of traffic accidents (Wang et al., 2013; Abel-Aty, 2003; Campbell et al., 2004) Similarly, traffic islands are typically installed near large intersections, and pedestrian traffic mainly occurs in those areas. As a result, the road width decreases at the point where a traffic island is installed, and traffic accidents caused by drivers unaware of this fact are frequently reported. Therefore, it can be expected that traffic islands and intersections may create complicated driving conditions and require rapid response, which, in turn, may lead to traffic accidents by elderly drivers.

[Table 3-6] Urban environmental indicator

Variable	Unit of a variable
School density	Number of schools including elementary, middle and high school (unit: thousand)/ area(㎢)
University density	Number of universities (unit: thousand)/ area(㎢)
Housing type ratio: Apartment	Number of apartments (unit: thousand house)/ area(㎢)
Housing type ratio: Detached house	Number of single-detached housings (unit: thousand house)/ area(㎢)
Proportion of land use type	Area of land use type (residential, commercial, industrial, green area)/area(㎢)
Mixed land use	$-\sum_{i}^{n}\frac{p_j \ln(p_j)}{\ln(J)}$ J= the number of land use type, p_j : occupied area ratio of the land use type I
School zone density	Number of school zones (unit: thousand)/ area(㎢)
Road extension	Road extension of target area (including expressway and national highway)
Subway density	Number of subway stations (unit: thousand)/ area(㎢)
Bus stop density	Number of bus stops (unit: thousand)/ area(㎢)
Intersection density	Number of intersections (unit: thousand)/ area(㎢)
Traffic island density	Number of traffic islands (unit: thousand)/ area(㎢)

- area: area of each administrative district

(3) Traffic accident feature

Among the items in the traffic accident data, the environmental condition of the accident site, the characteristics of the perpetrator, and the variables representing the accident situation are the factors that directly affect the number and severity of traffic accidents. In winter season characterized by snow and rain, the risk of accidents with a high injury severity also increases (Choi et al., 2009; Zhang et al., 2000; Park, 2015). However, since drivers are typically aware of the higher risk of an accident in bad weather conditions, the accident severity tends to increase in lower risk conditions (e.g., spring, autumn, clear weather) (Han and Park, 2011). The time is also expected to have a significant impact on traffic accidents, because it not only affects traffic volume but also relates to visibility of elderly drivers. Accident types and vehicle types also anticipated to have a significant impact on accident severity.

[Table 3-7] Traffic accident feature

Variable	Definition
Season	Spring: March to May , Summer: June to August Autumn: September to November, Winter: December to February
Daytime/Nighttime	Daytime: 6 am to before 6 pm Nighttime: 6 pm to before 6 am
Weekday/Weekend	Weekday: Monday to Friday Weekend: Saturday and Sunday
Weather	Based on the weather report of the Korea Meteorological Agency (Clear, Cloud, Rain, Fog, Snow, Etc.)
Road type	Single road, intersection, Others(tunnel, underpass, bridge, etc.)
Vehicle type of assailant	Passenger car, Van, Two-Wheeler, Prime-mover
Accident type	Car crashes, Pedestrian-vehicle accident, Single-car crash

[Table 3-8] shows the predicted effects of input variables on traffic accidents committed by elderly drivers.

[Table 3-8] Predicted effects of the input variables on traffic accidents by elderly drivers

Indicator	Variable	Predicted effect on traffic accident
Demographic and socioeconomic indicator	Population density	Increase in lower severity
	Household density	Increase in lower severity
	Population composition - Age under 20 population ratio - Age over 64 population ratio	- Age under 20 population ratio: increase in lower severity accident - Age over 64 population ratio: increase in severe accident
	Male population ratio	Increase in accident
	Transfer population ratio	Increase in severe accident
	Basic livelihood recipients ratio	Increase in severe accident
	Employee density	Increase in accident
	Business density	Increase in accident
Urban environmental indicator	School density	Increase in accident
	University density	Increase in accident
	Housing type ratio: Apartment	Increase in accident
	Housing type ratio: Detached house	Increase in lower severity accident
	Proportion of land use type (Residential, Commercial, Industrial, Green area)	- Increase in residential area and commercial area - Decease in industrial area and green area
	Mixed land use	Increase in accident
	Road extension	Increase in severe injury accident
	Public transportation accessibility (Bus stop density, Subway density)	Increase in accident
	School zone density	Decrease in accident
	Intersection density	Increase in severe accident
	Traffic island density	Increase in accident
Traffic accident feature	Season(Spring, Summer, Autumn, Winter)	Winter: increase in serious injury accident
	Daytime/Nighttime	Nighttime: increase in severe accident
	Weekday/Weekend	-
	Weather(Clear, Cloud, Rain, Fog, Snow, Etc.)	Rain, Snow : increase in injury severity
	Road type(Single road, Intersection, Others)	Intersection: increase in accident
	Vehicle type of assailant (Passenger car, Van, Two-wheeler, Prime-mover)	Two-wheeler, Prime-mover: increase in severe accident
	Accident type(Car crashes, Pedestrian-vehicle accident, Single-vehicle accident)	Pedestrian-vehicle: increase in serious injured accident

4. Construction of analysis data

The raw data of variables, which represents the demographic and socioeconomic indicator, was collected from the Seoul open data plaza and Seoul statistics.

In urban environmental indicator, housing type ratio was used Seoul housing type data from Seoul open data plaza. School density and university density used spatial data acquired from the National Spatial Data Infrastructure Portal and generated them as input variables through GIS mapping. Land use variables are based on the spatial data of urban ecology status in 2015. To investigate the impact of mixed land use attribute on traffic accidents the study used a concept of land use balance revised by Shannon(1948). Raw data for bus stop density and subway station density acquired from BIZ-GIS and Seoul metropolitan government big data campus. The road facilities(intersections and traffic islands) were collected through the official procedures from the management system of traffic safety facilities of Seoul. Most indicators in the urban environmental index were based on the spatial data. Therefore the research used GIS tool to sort spots into the analysis units. The unit of the variables is density and ratio. The density is a thousand units per each administrative area(㎢). Ratio(A/B) is the value occupied by A in B, and its minimum value is 0, and the maximum value is 1. The values in the research were rounded off the number to third decimal places.

[Table 3-9] Input data set

Variable		Year	Data source
Dependent variable : accident type by accident severity		2015	Korean National Police Agency
Demographic and socioeconomic indicator	Population density		Seoul open data plaza
	Household density		
	Population composition - Age under 20 population ratio - Age over 64 population ratio		
	Male population ratio		
	Transfer population ratio		
	Basic livelihood recipients ratio		
	Employee density		
	Business density		
Urban environmental indicator	School density	2016	National Spatial Data Infrastructure Portal, Bis-GiS Seoul open data plaza
	University density		
	Housing type ratio: Apartment	2015	Seoul statistics
	Housing type ratio: Detached house		
	Proportion of land use type (Residential, Commercial, Industrial, Green area)		Urban ecology status in 2015, National Spatial Data Infrastructure Portal
	Mixed land use		
	Road extension		Seoul metropolitan government big data campus, Road name address
	Public transportation accessibility (Bus stop density, Subway density)		Bis-Gis, Seoul metropolitan government big data campus
	School zone density	2016	Seoul open data plaza
	Intersection density	2015	Seoul T-GIS
	Traffic island density	2016	Bis-Gis
Traffic accident feature	Season(Spring, Summer, Autumn, Winter)	2015	Korean National Police Agency
	Daytime/Nighttime		
	Weekday/Weekend		
	Weather(Clear, Cloud, Rain, Fog, Snow, Etc.)		
	Road type(Single road, Intersection, Others)		
	Vehicle type of assailant (Passenger car, Van, Two-wheeler, Prime-mover)		
	Accident type(Car crashes, Pedestrian-vehicle accident, Single-vehicle accident)		

IV. The Characteristics of Urban Elderly Drivers' Traffic Accidents

1. Descriptive analysis

Among the dependent variables, 1.422 traffic accidents involving young elderly drivers(from 65 and 69 years old) and 1,049 traffic accidents involving middle- and old-elderly drivers group(above 69 years old) used in this analysis. For non-elderly drivers group(from 30 and 64 years old) utilized in the analysis. The number of accidents by injury severity in three age groups occurred in the order of minor injury accident〉 serious injury accident〉 injury accident〉 fatal accident. Among the age groups, fatal accident of 2015 in the young elderly drivers group took 1.69%, which is 1.97 times larger than that of non-elderly drivers group. Fatal accident committed by the middle- and old-elderly drivers group was 1.57 times greater than non-elderly drivers group.

[Table 4-1] Descriptive statistic of dependent variable

	Elderly drivers groups				Non-elderly drivers group	
	Young elderly drivers		Middle- and Old-elderly drivers			
	Freq.	Percent	Freq.	Percent	Freq.	Percent
Injury accident	80	5.63%	88	8.39%	856	6.98%
Minor injury accident	836	58.79%	613	58.44%	7,425	60.54%
Serious injury accident	436	33.9%	334	31.84%	3,879	31.63%
Fatal accident	24	1.69%	14	1.33%	105	0.86%
Total	1,422	100%	1,049	100%	12,265	100%

2. Collinearity review of the explanatory variables

The advantage of the logistic regression model is that it allows the study to investigate the influence by putting all explanatory variables simultaneously. However, since all variables entered into the model at once, the interaction between variables may occur. If multicollinearity, which has a strong correlation between independent variables, exists, the accuracy of the model will decrease, and the correlation between the independent variable and the dependent variable cannot be clearly grasped. Therefore, one of the variables with multicollinearity is left, and the rest is taken out of the input variables.

Since there is a possibility of a correlation between urban environmental, demographic, and socioeconomic factors, and accident features, multicollinearity problems cannot be avoided. For these reasons, the research confirmed the correlation between the variables before proceeding to the analysis. When the correlation between variables is more than 0.9, the problem will occur in the analysis. If the correlation is above 0.8, there is a possibility of a problem in the analysis. Among the explanatory variables, population density correlated with household density at 0.96; employee density correlated with business density (0.7) and commercial area ratio (0.72). The ordered logit model and the generalized ordered logit model automatically exclude variables that show multicollinearity in the early stages of the analysis. In the present study, the green area ratio which had the multicollinearity problem was excluded from the analysis.

Therefore, it excluded the variables of population density, employee density, and the green area ratio, which had high correlations with other variables. The final set of variables is shown in [Table 4-2].

[Table 4-2] The final set of explanatory variables

	Explanatory variables	Category
Demographic and socioeconomic indicator	Household density	
	Population composition - Age under 20 population ratio - Age over 64 population ratio	
	Male population ratio	
	Transfer population ratio	
	Basic livelihood recipients ratio	
	Business density	
Urban environmental indicator	School density	
	University density	
	Housing type ratio: Apartment	
	Housing type ratio: Detached house	
	Residential area ratio	
	Commercial area ratio	
	Industrial area ratio	
	Mixed land use	
	Road extension	
	Public transportation accessibility (Bus stop density, Subway density)	
	University density	
	School zone density	
	Intersection density	
	Traffic island density	
Accident feature	Season(0: Spring)	Summer(1), Autumn(2), Winter(3)
	Time(0:Daytime)	Nighttime(1)
	Date(0:Weekday)	Weekday(1)
	Weather(0: Clear)	Cloudy(1), Rain(2), Fog(3), Snow(4), Etc(5)
	Road type(0:Single road)	Intersection(1), Others(2)
	Vehicle type of assailant (0:Passenger car)	Van(1), Two-wheeler(2), Prime-mover(3)
	Accident type(0: Car crashes)	Pedestrian-vehicle accident(1), Single-vehicle accident(2)

3. Results of the ordered logit model

In this section, it reports the analysis results of the factors affecting severity of traffic accidents caused by elderly drivers (young elderly drivers and middle and old-elderly drivers) vs. non-elderly driver group using the ordered logit model. The results of the ordered logit model can be interpreted only on the premise that the parallel line assumption is satisfied. Therefore, a Brant test[13)] was run to test for parallel line assumption, i.e. the null hypothesis that the regression coefficients have the same value for all categories of dependent variables.

The results of the Brant test showed that the null hypothesis had to be rejected at the significance level of 1% in all three groups, which means that the interpreting the results of the ordered logit model may inadequate. Therefore, based on the results of the parallel line assumption, the application of the generalized ordered logit model is more appropriate [see Table 4-3].

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13) The Wald test designed by Brant(1990) allows for a verification of the parallel regression assumption for each of the variables.

[Table 4-3] Results of parallel line assumption test

Variables	Young elderly drivers group		Middle- and old-elderly drivers group		Non-elderly drivers group	
	X^2	p-value	X^2	p-value	X^2	p-value
All	122.21***	0.000	111.5***	0.000	437.73***	0.000
Household density	0.34	0.842	2.25	0.325	3.61	0.165
Male population ratio	3.41	0.181	3.86	0.145	2.73	0.255
Age over 64 population ratio	0.36	0.837	1.94	0.379	0.78	0.676
Age under 20 population ratio	1.99	0.369	1.59	0.452	0.81	0.667
Transfer population ratio	4.99*	0.083	21.68***	0.000	1.26	0.531
Basic Livelihood Recipients ratio	1.26	0.532	0.12	0.943	1.51	0.470
Business density	0.68	0.711	1.6	0.45	0.54	0.763
School density	0.4	0.818	4.78**	0.092	0.03	0.987
University density	1.86	0.395	0.89	0.64	0.34	0.842
Housing type ratio: Apartment	0.03	0.985	3	0.223	0.17	0.920
Housing type ratio: Detached house	3	0.223	3.79	0.151	1.19	0.552
Land use ratio: Residential area	2.03	0.362	5.51*	0.064	0.95	0.621
Land use ratio: Commercial area	0.14	0.932	1.84	0.399	0.09	0.956
Land use ratio: Industrial area	3.11	0.212	4.1	0.129	0.55	0.761
Mixed land use	1.49	0.474	6.79**	0.034	1.71	0.426
Road extension	0.11	0.948	2.39	0.303	0.50	0.779
Bus stop density	1.5	0.472	5.24*	0.073	0.08	0.960
Subway density	3.96	0.138	3.43	0.18	3.51	0.173
School Zone density	1.79	0.408	5.33*	0.07	2.65	0.266
Intersection density	7.8*	0.02	1.14	0.566	1.61	0.447
Traffic island density	0.95	0.621	0.83	0.662	0.29	0.867
Season(0: Spring)	8.39**	0.015	2.37	0.306	2.06	0.357
Weekend(0: Week)	0.91	0.634	1.86	0.395	5.98**	0.050
Nighttime (0:Daytime)	10.37***	0.006	3.84	0.147	1.93	0.381
Accident type (0: Car crash)	21.94***	0.000	5.85*	0.054	76.05***	0.000
Weather(0: Clear)	0.76	0.685	2.24	0.327	0.81	0.667
Road type (0: Single road)	0.55	0.761	1.29	0.523	3.89	0.143
Vehicle type (0: Passenger car)	48.39***	0.000	24.23***	0.000	263.31***	0.000

p<0.1 : *, p<0.05:**, p<0.01: ***

4. Results of the generalized ordered logit model

It then used the generalized ordered logit model to investigate the accident characteristics according to injury severity of accidents among young elderly drivers [see Table 4-4], the middle- and old-elderly drivers group [Table 4-5], and the non-elderly drivers group [Table 4-6]. In each table, the results of the ordered logit modeling are shown with the results of the generalized ordered logit model. The ordered logit model has the same regression coefficient value applied to the entire category of dependent variables and can be expressed by a single column. On the other hand, the generalized ordered logit model examines how the influence of each factor on the accident severity varies depending on the set of the concern group. Tables 4-4, 4-5, 4-6 illustrate the results of applying the composition of the control group and the interest group differently from column [A] to column [C] in the analysis of each age group.

Column [A] shows the odds ratio and coefficient of the injury accident vs. minor injury accident, serious injury accident, or fatal accident. Column [B] indicates the odds ratio and coefficient value of the injury accident or minor injury accident vs. serious injury accident or fatal accident. Finally, Column [C] reports the value of odds ratio and coefficient by injury accident, minor injury accident, and serious injury accident vs. fatal accident. By subdividing the elderly drivers into the two groups, it could selectively examine appropriate suggestions by age group according to the subject of policy (Lee and Kim, 2015). For example, if the subjects of the policy are serious injury accident and fatal accident, the analysis of column [B] will provide useful information. The results of the analysis show the differences in the direction and magnitude of the influence of the factors affecting injury severity of young elderly drivers, middle- and old-elderly drivers, and non-elderly drivers. Detached house ratio, subway density, accident type, and vehicle type were common factors affecting traffic accidents in all age groups. Among the types of traffic accidents, the pedestrian-vehicle accident was found to be positively associated with serious injury accident or fatal accident (Column[B]). The pedestrian-vehicle accident may lead to more casualties, as the mortality rate in this type of accidents is 70% higher than in car crashes. The transfer population ratio reduced injury severity in the young elderly drivers and middle-and old-elderly drivers group. The business density was found to be positively associated with serious or fatal accidents in middle- and old-elderly drivers. With an increase in business density by one unit, the possibility of severe accidents among middle- and old-elderly drivers increased by 10%.

The impact of serious or fatal accidents varied depending on land use types. When the proportion of industrial areas increased by one unit, the probability of serious or fatal accidents in the young elderly group decreased by 86%. In the residential area; when the residential area ratio increased by one unit, the possibility of severe accidents committed by middle- and old-elderly drivers decreased by 56.4%. In the non-elderly drivers group, with an increase of the ratio of commercial areas by one unit, the risk of serious or fatal accidents decreased by 32%.

Another factor that has a significant effect on the number and severity of traffic accidents is housing type. Apartment ratio exerts an adverse effect on the number of fatal accidents among middle- and old-elderly drivers, while there was no statistically significant effect on young-elderly drivers groups. When the detached house ratio increased by one unit, the probability of serious or fatal accidents caused by middle- and old-aged elderly drivers decreased by 84.4%; however, the probability of occurrence of non-aged drivers rose by 52.3%.

For the elderly driver groups, the accident occurrence time has a significant impact on serious accidents or fatal accidents. In both elderly groups (the young and the middle/ old-aged), the severe accidents had an 80% higher risk to occur at nighttime than in the daytime.

Public transport accessibility (subway density and bus station density) has an important impact on the number of fatal accidents (Column[C]) among elderly drivers groups. In the young elderly drivers group, the subway density was found to be a risk factor in fatal accidents. Furthermore, in the middle- and old-elderly drivers groups, the risk of fatal accidents increased in the areas with the highest bus density. Among the road types, intersections were 71% more likely to lead to fatal accidents in the young elderly drivers group than in the single roads.

Mixed land use was not found to have a significant effect on the number and severity of traffic accidents committed by the non-elderly drivers group; however, it affected both elderly drivers groups. Mixed land use is negatively correlated with injury accident vs. minor injury accident, serious injury accident, or fatal accident. However, it also leads to fatal accidents in the middle- and old-elderly drivers groups. Furthermore, the areas with a mixed land use show heavy traffic. This complex environment is predicted to negatively affect driving of middle and old-elderly drivers.

The results of the analysis using the ordered logit model and the generalized ordered logit model had significant differences in the values and directions of affecting variables.

As the results of the Likelihood ratio test[14] between the generalized ordered logit model and the ordered logit model, the likelihood difference was significant at the confidence interval of 99%, indicating that the generalized ordered logit model is more suitable for this analysis than the ordered logit model. The difference of the explanatory power of the analytical models was shown. The pseudo-R^2 in the ordered logit model of the young elderly driver was 0.052, while that of the generalized ordered model was 0.108. In the middle- and old-elderly drivers, group the pseudo-R^2 of the ordered logit model was 0.044, while that of the generalized ordered model was 0.115. In the non-elderly drivers group, pseudo-R^2 increased from 0.016 in the ordered logit model to 0.034 in the generalized ordered model.

14) A Likelihood ratio test(LR test) is a statistical test used to compare the goodness of fit of two statistical models - a null model against an alternative model.

[Table 4-4] Results of analysis of the accident severity by Young elderly drivers group using the generalized ordered logit model

	Variables	Ordered logit model		Generalized ordered logit model					
				Coefficient			Odds Ratio		
		Coef.	Odds Ratio	[A]	[B]	[C]	[A]	[B]	[C]
Demographic and Socioeconomic indicator	Housing density	0.034	1.035	0.055	0.036	-0.025	1.057	1.037	0.975
	Male population ratio	0.625	1.868	-10.011*	1.980	23.424	4.E-05*	7.243	1.E+10
	Age over 64 population ratio	-4.117	0.016	-1.781	-4.287	11.459	0.168	0.014	9.E+04
	Age under 20 population ratio	-0.208	0.812	8.843	-1.024	13.434	6925.739	0.359	7.E+05
	Transfer population ratio	-3.914**	0.020**	1.422	-3.567**	-27.863***	4.145	0.028**	8.E-13***
	Basic livelihood recipients ratio	6.907**	999.205 **	18.865**	6.008	-19.566	2.00E+08 **	406.669	3.E-09
	Business density	-0.051	0.950	-0.116	-0.037	-0.233	0.89	0.964	0.792
Urban environmental indicator	School density	-32.313	9.E-15	-71.465	-28.481	70.801	9.00E-32	4.E-13	6.E+30
	University density	-16.562	6.E-08	-296.755	-23.625	874.166*	1.00E-129	5.E-11	*
	Housing type ratio: Apartment	0.560*	1.750*	1.060	0.552	-0.333	2.886	1.737	0.717
	Housing type ratio: Detached house	1.388**	4.006**	5.155***	1.066	1.627	173.296***	2.904	5.089
	Residential area ratio	-0.453	0.636	0.729	-0.599	-2.582	2.073	0.549	0.076
	Commercial area ratio	0.358	1.431	1.563	0.114	0.358	4.773	1.121	1.430
	Industrial area ratio	-1.212	0.298	2.895	-1.985*	0.773	18.084	0.137*	2.166
	Mixed land use	-0.766*	0.465*	-1.080	-0.798*	0.753	0.34	0.450*	2.123
	Road extension	-0.016	0.984	-0.008	-0.012	-0.052	0.992	0.988	0.949
	Bus stop density	-7.317	0.465	-20.098	-5.003	1.282	2.E-09	0.007	3.604
	Subway density	80.357	0.984	149.602	54.873	721.960***	9.E+64	7.E+23	***
	School Zone density	-30.990	0.001	-7.663	-44.830	209.757	5.E-04	3.E-20	1.E+91
	Traffic island density	13.316	8.E+34	159.530***	-3.378	2.802	2.E+69***	0.034	16.478
	Intersection density	4.039	3.E-14	-33.085	7.273	24.164	4.E-15	1440.578	3.E+10
Accident feature	Season(0: Spring)								
	1. Summer	-0.169	0.844	-0.476	-0.140	-0.422	0.621	0.382	0.656
	2. Autumn	-0.126	0.881	-0.973***	-0.040	0.857	0.378***	0.360	2.356
	3. Winter	0.068	1.071	-0.406	0.017	1.829***	0.666	0.393	6.228***
	Weekend(0: Week)	0.004	1.004	-0.154	0.012	0.376	0.857	0.284	1.456
	Night time(0: Daytime)	0.396***	1.486***	0.163	0.363***	2.148***	1.177	1.438***	8.568***
	Accident Type(0: Cars crash)								
	1. Pedestrian-vehicle	0.963***	2.620***	-0.163	1.010***	2.691***	0.850	2.746***	14.746***
	2. Single vehicle accident	0.552*	1.737*	-0.007	0.545*	2.815***	0.993	1.725*	16.693***
	Weather(0: Clear)								
	1. Rainy	-0.096	0.909	-0.510	0.040	-1.254	0.600	1.041	0.285
	2. Cloud	-0.092	0.912	-0.154	-0.082	0.219	0.857	0.921	1.245
	3. Snow	0.304	1.356	13.322	0.386	-14.462	6.E+05	1.471	5.E-07
	4. Fog	-0.2	0.819	-2.256*	0.293	-13.538	0.105*	1.340	1.E-06
	Road Type(0: Single road)								
	1. Intersection	0.186	1.204	0.389	0.131	0.918*	1.476	1.140	2.504*
	2. Others	-0.723**	0.485**	-1.148**	-0.436	-12.282	0.317**	0.647	5.E-06
	Vehicle type(0: Passenger Car)								
	1. Van	0.557***	1.745***	1.191	0.495**	1.415**	3.290	1.640**	4.116**
	2. Two-wheeler	-0.626*	0.535*	-2.227***	0.188	-12.602	0.108***	1.207	3.E-06
	3. Prime mover	-1.40***	0.247***	-3.152***	-0.126	-12.767	0.043***	0.882	3.E-06
Constants				5.49	-0.66	-20.11*	241.77	0.52	2.E-09*
Pseudo R^2		0.052		0.108					
LR likelihood		145.17***							
Number of observations		1,422							

[A] Injury accident (control group) vs Minor injury accident, Serious injury accident or Fatal accident (interest group)
[B] Injury accident or Minor injury accident (control group) vs Serious injury accident or Fatal accident (interest group)
[C] Injury accident, Minor injury accident, Serious injury accident (control group) vs Fatal accident (interest group)
$p<0.1$: *, $p<0.05$:**, $p<0.01$: ***
Unit of density: (thousand/㎢), Unit of ratio: a/b = 0(minimum value) ~ 1(maximum value)

[Table 4-5] Results of analysis of the accident severity by Middle- and Old-elderly drivers group using the generalized ordered logit model

	Variables	Ordered logit model		Generalized ordered logit model					
		Coef	Odds Ratio	Coefficient			Odds Ratio		
				[A]	[B]	[C]	[A]	[B]	[C]
Population Socioeconomic indicator	Housing density	0.049*	1.051*	0.073	0.061**	-0.058	1.076	1.063***	0.944
	Male population ratio	-2.856	0.058	-6.69	-3.301	45.21	0.001	0.037	4.3.E+19
	Age over 64 population ratio	4.980	145.413	6.647	4.726	-16.696	770.469	112.843	5.6.E-08
	Age under 20 population ratio	1.582	4.863	7.885	-1.228	7.82	3.E+03	0.293	2489.91
	Transfer population ratio	-4.052**	0.017**	10.686*	-9.591***	14.26	4.E+04*	0.0001 ***	2.E+06
	Basic livelihood recipients ratio	4.122	61.678	2.025	3.727	-3.287	8.E+00	41.554	0.037
	Business density	0.064	1.067	0.101	0.097**	-0.278	1.106	1.102**	0.757
Urban environmental indicator	School density	20.704	1.E+09	93.933	13.098	-553.1**	6.E+40	5.E+05	6.E-241**
	University density	161.388	1.23E+70	659.534	78.672	410.929	3.E+286	1.E+34	3.E+178
	Housing type ratio: Apartment	-0.035	0.966	0.443	-0.093	-3.899*	1.557	0.911	0.020*
	Housing type ratio: Detached house	-1.056	0.348	0.868	-1.856**	-3.272	2.382	0.156**	0.038
	Residential area ratio	-0.713*	0.490*	-3.057**	-0.829*	3.181	0.047**	0.436*	24.071
	Commercial area ratio	-0.639	0.528	-2.139	-1.075	-5.766	0.118	0.341	0.003
	Industrial area ratio	0.564	1.757	-1.907	0.894	-1.174	0.149	2.445	0.309
	Mixed land use	-0.192	0.825	-1.974*	-0.124	6.905*	0.139*	0.883	997.249*
	Road extension	-0.012	0.988	-0.025	-0.007	-0.801	0.975	0.993	0.449
	Bus stop density	-3.955	0.019	-10.187	-6.818	75.015*	4E-05	0.001	4.E+32*
	Subway density	-112.488	1.403E-49	-367.089***	-55.491	-125.75	4E-160***	8.E-25	2.E-55
	School Zone density	-46.075	9.768E-21	-160.528**	-15.988	122.198	2E-70**	1.E-07	1.E+53
	Traffic island density	19.635	3.E+08	-0.282	46.537*	-147.28	0.7543	2.E+20*	1.E-64
	Intersection density	-17.197	3.401E-08	-26.862	-20.04	14.114	2E-12	2.E-09	1.E+06
Accident feature	Season(0:Spring)								
	1. Summer	-0.002	0.998	-0.305	0.061	1.173	0.737	1.063	3.232
	2. Autumn	-0.020	0.980	-0.183	-0.014	1.038	0.833	0.986	2.824
	3. Winter	-0.013	0.987	-0.336	0.022	1.669	0.715	1.022	5.307
	Weekend(0: Week)	0.079	1.083	0.051	0.07	-1.657	1.052	1.073	0.191
	Night time(0: Daytime)	0.082	1.085	-0.128	0.093	1.668**	0.880	1.097	5.302**
	Accident Type(0: Cars crash)								
	1. Pedestrian-vehicle	0.712***	2.038***	0.37	0.765***	2.371**	1.448	2.149***	10.708**
	2. Single vehicle accident	0.084	1.087	-0.1	0.033	3.644**	0.905	1.034	38.245**
	Weather(0: Clear)								
	1. Rain	0.219	1.244	-0.049	0.179	-15.652	0.952	1.196	2.E-07
	2. Cloud	0.243	1.276	0.364	0.19	-0.894	1.439	-0.153	0.409
	3. Snow	0.112	1.118	15.667	-0.153	-14.401	6.E+06	0.858	6.E-07
	4. Fog	0.636	1.888	15.215	0.562	-11.624	4.E+06	1.754	9.E-06
	Road Type(0: Single road)								
	1. Intersection	0.102	1.107	0.149	0.124	0.716	1.161	1.132	2.04623
	2. Others	0.078	1.081	15.806	-0.544	3.091	7.E+06	0.580	21.9991
	Vehicle type(0: Passenger Car)								
	1. Van	0.476	1.610	-0.535	0.566*	0.716	0.586	1.761*	2.046
	2. Two-wheeler	-1.188***	0.305***	-1.956***	-0.795**	3.091**	0.141***	0.452**	21.999*
	3. Prime mover	-0.912**	0.402**	-1.715***	-0.241	-9.695	0.180***	0.786	6.E-05
Constants				5.756	2.284	-32.926*	316.081	9.816	5E-15*
Pseudo R^2		0.044		0.115					
LR likelihood		140.63***							
Number of observations		1.049							

[A] Injury accident (control group) vs Minor injury accident, Serious injury accident or Fatal accident (interest group)
[B] Injury accident or Minor injury accident (control group) vs Serious injury accident or Fatal accident (interest group)
[C] Injury accident, Minor injury accident, Serious injury accident (control group) vs Fatal accident (interest group)
p<0.1 : *, p<0.05:**, p<0.01: ***
Unit of density: (thousand/㎢), Unit of ratio: a/b = 0(minimum value) ~ 1(maximum value)

[Table 4-6] Results of analysis of the accident severity by Non-elderly drivers group using the generalized ordered logit model

	Variables	Ordered logit model		Generalized ordered logit model					
		Coef	Odds Ratio	Coefficient			Odds Ratio		
				[A]	[B]	[C]	[A]	[B]	[C]
Population Socioeconomic indicator	Housing density	0.005	1.005	0.013	0.001	0.064	1.013	1.001	1.066
	Male population ratio	0.750	2.116	2.755	0.297	8.814	15.721	1.346	7.E+03
	Age over 64 population ratio	1.062	2.893	0.524	1.2	-2.734	1.689	3.320	0.065
	Age under 20 population ratio	1.040*	2.830*	-0.222	1.239*	2.299	0.801	3.452*	9.964
	Transfer population ratio	0.547	1.728	1.252	0.499	-1.333	3.497	1.647	0.264
	Basic livelihood recipients ratio	-1.286	0.276	-5.297	-0.367	-2.333	0.005	0.693	0.097
	Business density	-0.001	0.999	0.002	-0.001	-0.035	1.002	0.999	0.966
Urban environmental indicator	School density	-5.876	0.003	-2.902	-5.342	-13.372	0.055	5.E-03	0.000
	University density	-112.52**	1.36E-49 **	-67.98	-115.26**	-194.61	3.E-30	9.E-51**	3.E-85
	Housing type ratio: Apartment	0.069	1.072	0.053	0.082	-0.074	1.054	1.085	0.929
	Housing type ratio: Detached house	0.398**	1.489**	0.157	0.421*	1.214	1.170	1.523*	3.367
	Residential area ratio	-0.222*	0.801*	-0.282	-0.19	-0.743	0.754	0.827	0.476
	Commercial area ratio	-0.361**	0.697**	-0.823	-0.386**	-1.014	0.439	0.680**	0.363
	Industrial area ratio	-0.317	0.729	0.161	-0.417	-1.077	1.175	0.659	0.341
	Mixed land use	0.0457	1.047	-0.224	0.124	-0.029	0.799	1.132	0.971
	Road extension	-0.001*	0.9995*	-0.001*	-0.0004	-0.029	0.999*	0.9996	0.971
	Public transportation accessibility density(thousand/㎢)								
	Bus stop density	2.157	8.643	1.906	2.304	-3.79	2.E-02	10.014	2.E-02
	Subway density	-22.470	1.74E-10	-87.851**	-7.609	26.784	4.3E+11**	0.0005	4.E+11
	School Zone density	-5.411	0.004	5.663	-3.551	-97.97	2.833E-43	0.029	3.E-43
	Traffic island density	0.184	1.202	6.253	-1.35	27.727	1.101E+12	0.259	1.E+12
	Intersection density	0.029	1.029	1.556	-0.749	9.596	14705.840	0.473	1.E+04
Accident feature	Season(0:Spring)								
	1. Summer	-0.056	0.945	-0.139	-0.036	-0.179	0.870	0.965	0.836
	2. Autumn	-0.139**	0.870**	-0.307***	-0.098	-0.154	0.736***	0.907	0.857
	3. Winter	-0.105**	0.900**	-0.192*	-0.089*	-0.072	0.825*	0.915*	0.931
	Weekend(0: Week)	0.064	1.066	-0.104	0.098**	0.067	0.901	1.103**	1.069
	Night time (0: Daytime)	0.038	1.039	0.033	0.03	0.332	1.034	1.030	1.394
	Accident Type(0: Cars crash)								
	1. pedestrian-vehicle	0.653***	1.921***	0.122	0.714***	1.597***	1.130	2.042***	4.938***
	2. Single vehicle accident	0.071	1.073	-0.545***	0.238***	1.032***	0.580***	1.269***	2.807***
	Weather(0: Clear)								
	1. Rain	0.076	1.079	-0.264	0.129	0.415	0.768	1.138	1.514
	2. Cloud	0.168**	1.183**	0.178	0.165**	0.24	1.195	1.179**	1.271
	3. Snow	1.188	3.282	11.877	1.193	-10.515	1.4.E+05	3.297	2.7E-05
	4. Fog	-0.378	0.685	-0.931*	-0.144	-11.601	0.394*	0.866	9.2E-06
	5. Etc	-0.134	0.875	-0.146	-0.142	0.353	0.864	0.868	1.423
	Road Type(0: Single road)								
	1: Intersection	0.102***	1.107***	0.052	0.125***	-0.338	1.053	1.133***	0.713
	2: Others	-0.008	0.992	0.165	-0.047	-0.098	1.179	0.954	0.907
	Vehicle type(0: Passenger Car)								
	1. Van	0.180***	1.198***	-0.101	0.212***	0.658**	0.904	1.236***	1.931**
	2. Two-wheeler	-0.556***	0.573***	-1.547***	-0.075	0.551*	0.213***	0.928	1.735*
	3. Prime mover	-0.246	0.782	-1.482***	0.228	1.007	0.227***	1.256	2.737
Constants				1.747	-1.55**	-9.68***	5.74	0.21**	6.6E-05***
Pseudo R^2		0.016		0.034					
LR likelihood		386.53***							
Number of observations		12,265							

[A] Injury accident (control group) vs Minor injury accident, Serious injury accident or Fatal accident (interest group)
[B] Injury accident or Minor injury accident (control group) vs Serious injury accident or Fatal accident (interest group)
[C] Injury accident, Minor injury accident, Serious injury accident (control group) vs Fatal accident (interest group)
p<0.1 : *, p<0.05:**, p<0.01: ***
Unit of density: (thousand/㎢), Unit of ratio: a/b = 0(minimum value) ~ 1(maximum value)

The marginal effect analysis was conducted to examine the characteristics of accidents among elderly drivers according to injury severity. The marginal effect provides a fine approximation to the amount of change in Y (dependent variable) that will be produced by 1-unit changes in X_k. It is a description of the probabilistic change in the variation of the different independent variables for each category of the dependent variable. The results of the marginal effect analysis of three age groups focused on the variables that were significant for each indicator.

5. Factors affecting injury severity

1) Demographic and socioeconomic indicator

Among the demographic attributes, the variables which affect the highly dense and traffic volume influence to occur accidents by elderly drivers. For example, household density was found to be positively correlated with serious injury accidents by middle- and old-elderly drivers. LaScala et al.(2000) and Hadeyegi et al.(2003) argued that household density affected to increase traffic volume and frequent conflicts between vehicles. As the traffic volume increased due to increasing household density, the risk of unexpected situations (illegal parking, obstruction of sight, illegal crossing) during driving may also increase. It can lead to a serious injury accident by middle-and old-elderly drivers who are unable to quickly evaluate the road situation and respond appropriately.

Business density also contributed to the increase in serious injury accidents of the middle and old-elderly drivers groups; specifically, when business density increased by one unit, the probability of a serious injury accident rose by 2.3%. Commercial facilities and distribution companies are concentrated in the areas with a high business density, and it increased traffic volume which, in turn, affected the number of serious injury accidents in the young elderly group.

The male population ratio was also found to be a risk factor. Specifically, when the male population ratio increased by one unit, the possibility of an injury accident increased by 62.1%.

In the elderly driver groups, the specific age population ratio did not have a significant influence on accident severity. On the other hand, the proportion of the population aged under 20 has a significant influence on the injury accident and serious injury accident of non-elderly drivers. When the proportion of drivers aged under 20 increases by a single unit, the probability of injury accident is reduced by 24.3%, while the risk of a serious injury accident increases by 27.8%.

The transfer population ratio was also found to affect the injury severity of elderly driver groups. The transfer population ratio was positively associated with minor injury accident in elderly drivers groups. According to the Korea Labor Institute's 'Interregional Population Migration and Regional Employment Report'[15], although there are differences in factors influencing the influx of the population by age, employment opportunities, integrated economic benefits, child-care and educational conditions are common factors, which selected as main reason of the migration. Therefore, an urban area with a large number of migrants has a substantial population and facilities (schools, businesses, commercial facilities, etc.) which can cause traffic. This feature

15) Kang(2016), Interregional Population Migration and Regional Employment Report, Korea Labor Institute.

can have affected the traffic accidents of elderly drivers. The basic livelihood recipients ratio affects the injury severity of the young elderly drivers group. While it has a negative effect on the number of injury accidents, it is positively related to serious injury accidents.

As for the impact of poverty on the number of traffic accident, Huang et al. (2010) found that in low-income areas, the number of traffic accidents increased because the risk of insecure behavior in those areas is higher than that observed in high-income areas.

[Table 4-7] Result of marginal effect on demographic and socioeconomic indicator

	Odds ratio											
	Elderly drivers groups								Non-elderly drivers group			
	Young-elderly drivers				Middle- and Old-elderly drivers							
Variables	Injury accident	Minor injured accident	Serious injured accident	Fatal accident	Injury accident	Minor injured accident	Serious injured accident	Fatal accident	Injury accident	Minor injured accident	Serious injured accident	Fatal accident
Household density	0.997 (-0.003)	0.995 (-0.005)	1.008 (0.008)	0.9996 (-0.0004)	0.995 (-0.005)	0.993 (-0.007)	1.013** (0.013)	0.999 (-0.001)	0.999 (-0.001)	1.001 (0.001)	0.9997 (-0.0003)	1.001 (0.001)
Male population ratio	1.621* (0.483)	0.406 (-0.901)	1.080 (0.077)	1.406 (0.341)	1.589 (0.463)	1.231 (0.208)	0.305 (-1.187)	1.675 (0.516)	0.842 (-0.172)	1.115 (0.109)	0.990 (-0.010)	1.076 (0.074)
Age over 64 population ratio	1.090 (0.086)	2.266 (0.818)	0.343 (-1.071)	1.181 (0.343)	0.631 (-0.460)	0.606 (-0.501)	3.161 (1.151)	0.827 (-0.190)	0.968 (-0.033)	0.800 (-0.223)	1.322 (0.279)	0.977 (-0.023)
Age under 20 population ratio	0.653 (-0.427)	1.902 (0.643)	0.663 (-0.411)	1.216 (0.195)	0.580 (-0.546)	2.215 (0.795)	0.713 (2.215)	1.093 (0.089)	1.014 (0.014)	0.757* (-0.278)	1.278* (0.245)	1.019 (0.019)
Transfer population ratio	0.934 (-0.069)	2.273** (0.821)	0.707 (-0.347)	0.667** (-0.405)	0.478* (-0.739)	14.717*** (2.689)	0.121*** (-2.112)	1.177 (0.163)	0.925 (-0.078)	0.972 (-0.028)	1.125 (0.118)	0.989 (-0.011)
Basic livelihood recipients ratio	0.402** (-0.911)	0.700 (-0.356)	4.716* (1.551)	0.752 (-0.284)	0.869 (-0.140)	0.539 (-0.617)	2.214 (0.795)	0.963 (-0.037)	1.392 (0.311)	0.777 (-0.252)	0.943 (-0.059)	0.981 (-0.019)
Business density	1.006 (0.006)	1.002 (0.002)	0.996 (-0.004)	0.997 (-0.003)	0.993 (-0.003)	0.987 (-0.013)	1.023** (0.023)	0.997 (-0.003)	0.9999 (-0.0001)	1.0004 (0.0004)	1.0001 (0.0001)	0.9997 (-0.0003)

(x): x refers coefficient
p〈0.1 : *, p〈0.05:**, p〈0.01: ***

2) Urban environmental indicator

In the present study, in order to explore the correlations of urban factors with injury severity in traffic accidents of elderly drivers, the researcher investigated urban environmental factors. Except for apartment ratio and intersection density, all urban environmental factors were found to affect injury severity.

School density was found to have a negative influence on the number of fatal accidents in the middle- and old-elderly drivers group, whereas the school zone density was positively associated with the number of injury accidents committed by the middle- and old-elderly drivers. Furthermore, school zones are typically installed on the roads near the facilities for children under the age of 13. The initial prediction of the present study was that there would be a negative correlation between injury severity and the number of schools, as, in such areas, drivers tend to recognize the school zone signs and drive carefully. However, with an increase of the age of elderly drivers, physical aging, a decrease in the useful field of view, and hearing may lead to an increase in the number of traffic accidents due to drivers' inability to recognize children, due to their small height, in blind spots. Of note, compared to adults, young children also have lower traffic safety awareness. Although elderly drivers drive carefully in school zones, it acts as a risk factor to increase the possibility of injury accidents.

Among the housing type, the effect of detached house ratio shows differences between age of the groups. In middle- and old-elderly drivers group and non-elderly drivers group, it acted as a risk factor to increase the probability of accident occurrence.

However, in the young elderly drivers group, detached house ratio decreased the probability of injury accidents.

The proportion of residential area was found to increase accident severity in the elderly driver groups. In the young elderly drivers group, the probability of minor injury accident increased by 17.5% when the residential area ratio increased by one unit, and the probability of injury accident increased by 23.5% in the middle and old elderly drivers. A residential area is a primary living space for urban residents, and neighborhood facilities and cultural and sports facilities are installed together to fulfill the minimum conditions for life. The residential area has a high population density, vehicle traffic, and pedestrian traffic at various age groups, which has a significant impact on the number of traffic accidents committed by elderly drivers.

Commercial areas affected the number of traffic accidents among non-elderly drivers. When the number of commercial areas increased by one unit, the probability of a serious accident among the non-elderly drivers decreased by 7.1%. The decreasing possibility of an accident could have been affected by a lower driving speed due to the high traffic volume in commercial areas.

The proportion of industrial areas is another risk factor that influences severity of accidents among young elderly drivers. Heavy vehicles, such as trucks and construction machinery, mainly pass through industrial areas, and it appears that the characteristics of heavy vehicles disturb drivers secure of sight while driving.

Mixed land use affects accident severity of elderly drivers. In the middle- and old-elderly driver group, when the mixed land use rose by one unit, the risk of an injury accident increased by

14.6%, and the risk of fatal accident increased by 8.2%. On the other hand, mixed land use reduced the probability of serious injury accidents by young elderly drivers. The characteristics of mixed land use areas, which have a dense population and pedestrian traffic, affects older elderly drivers.

Road extension was found to be positively related to the number of injury accidents committed by non-elderly drivers and it is in accord with the previous studies(Park et al., 2013; Kim and Park, 2010). With an increase of the length of the road extension, new road facilities generate an increase in the traffic volume, which increases the risk of traffic accidents (Kim et al., 2017).

Subway density and bus station density, which relate to public transport accessibility, have a significant impact on injury severity. Subway density affects the traffic accidents (particularly injury accidents and fatal accidents) among drivers from all three age groups. Furthermore, bus stop density raises the risk of fatal accidents caused by middle- and old-elderly drivers. When the bus-stop density increased by one unit, the probability of a fatal accident among this driver group increased by 135%. The use of public transport also increases the risk of exposure to traffic accidents, and the difficulties in securing visibility for elderly drivers due to the installation of bus-only lanes and bus traffic appear to affect the number of fatal accidents (Jeong, 2015; Rlee, 2016).

Traffic island density affects injury severity of the elderly drivers groups as compared to the non-elderly drivers. Traffic island density is a risk factor that increases the risk of minor injury accidents committed by young elderly drivers, and the number of serious injury accidents committed by middle- and old-elderly drivers. Traffic island is a traffic facility installed near a large intersection and used by pedestrians. At the point where a traffic island is installed, the width of the road tends to narrow, and it disturbs the traffic flow. Considering that elderly drivers need longer response time than non-elderly drivers, the risk of a serious injury seems to be increased for the former group. Therefore, with an increase in drivers' age, the traffic island density increases the number and severity of traffic injuries.

[Table 4-8] Result of marginal effect on urban environmental indicator

	Odds ratio											
	Elderly drivers groups								Non-elderly drivers group			
	Young-elderly drivers				Middle- and Old-elderly drivers							
Variables	Injury accident	Minor injured accident	Serious injured accident	Fatal accident	Injury accident	Minor injured accident	Serious injured accident	Fatal accident	Injury accident	Minor injured accident	Serious injured accident	Fatal accident
School density	31.506 (3.450)	12.886 (2.556)	0.001 (-7.036)	2.799 (1.029)	0.002 (-6.498)	46.352 (3.836)	8.E+03 (8.971)	0.002* (-6.308)	1.199 (0.181)	2.609 (0.959)	0.358 (-1.029)	0.894 (-0.112)
University density	2E+06 (14.327)	9.E-05 (-9.345)	2.E-08 (-17.690)	3.E+05 (12.708)	2.E-20 (-45.614)	7.E+12 (29.622)	8.E+04 (11.304)	108.511 (4.687)	69.599 (4.243)	7.E+08* (20.354)	1.E-10** (-22.973)	0.197 (-1.623)
Apartment ratio	0.950 (-0.051)	0.937 (-0.065)	1.129 (0.121)	0.995 (-0.005)	0.970 (-0.031)	1.051 (0.050)	1.026 (0.025)	0.957 (-0.044)	0.997 (-0.003)	0.986 (-0.014)	1.018 (0.018)	0.999 (-0.001)
Detached house ratio	0.780*** (-0.249)	1.024 (0.024)	1.223 (0.201)	1.024 (0.024)	0.942 (-0.060)	1.548** (0.437)	0.712* (-0.340)	0.963 (-0.037)	0.990 (-0.010)	0.923* (-0.080)	1.083* (0.080)	1.010 (0.010)
Residential area ratio	0.965 (-0.035)	1.175* (0.161)	0.915 (-0.089)	0.963 (-0.038)	1.235** (0.211)	0.958 (-0.043)	0.815** (-0.205)	1.037 (0.036)	1.018 (0.018)	1.023 (0.023)	0.966 (-0.034)	0.994 (-0.006)
Community area ratio	0.927 (-0.075)	1.053 (0.051)	1.019 (0.019)	1.005 (0.005)	1.160 (0.148)	1.073 (0.071)	0.858 (-0.153)	0.936 (-0.066)	1.024 (0.024)	1.060 (0.058)	0.929** (-0.074)	0.992 (-0.008)
Industrial area ratio	0.870 (-0.140)	1.748** (0.558)	0.651* (-0.430)	1.011 (0.011)	1.141 (0.132)	0.731 (-0.314)	1.215 (0.195)	0.987 (-0.013)	0.990 (-0.010)	1.104 (0.099)	0.923 (-0.080)	0.991 (-0.009)
Mixed land use	1.054 (0.052)	1.123 (0.116)	0.836* (-0.179)	1.011 (0.011)	1.146* (0.137)	0.895 (-0.111)	0.901 (-0.104)	1.082* (0.079)	1.014 (0.014)	0.960 (-0.040)	1.027 (0.027)	0.9998 (-0.0002)
Road Extension	1.0004 (0.0004)	1.002 (0.002)	0.998 (-0.002)	0.999 (-0.001)	1.002 (0.002)	0.9998 (-0.0002)	1.008 (0.008)	0.991 (-0.009)	1.0001* (0.0001)	1.00003 (0.00003)	0.99992 (-0.0001)	0.000 (0,000)
Bus density	2.639 (0.970)	1.088 (0.085)	0.342 (-1.074)	1.019 (0.019)	2.023 (0.705)	1.976 (0.681)	0.106 (-2.241)	2.353* (0.856)	0.888 (-0.119)	0.689 (-0.373)	1.688 (0.523)	0.969 (-0.032)
Subway density	0.001 (-7.223)	0.013 (-4.350)	2.936 (1.077)	4.E+04** (10.495)	1.E+11*** (25.396)	7.E-07 (-14.117)	0.0001 (-9.845)	0.238 (-1.434)	240.607** (5.483)	0.021 (-3.860)	0.158 (-1.847)	1.250 (0.223)
School zone density	1.448 (0.370)	8814.514 (9.084)	4.E-06 (-12.503)	21.099 (3.049)	7.E+04** (11.106)	4.E-04 (-7.856)	0.010 (-4.643)	4.030 (1.394)	0.702 (-0.353)	3.038 (1.111)	1.061 (0.059)	0.442 (-0.817)
Traffic island density	5.E-04*** (-7.702)	4510.206* (8.414)	0.471 (-0.753)	1.042 (0.041)	1.020 (0.019)	8.E-05** (-9.479)	7.E+04** (11.139)	0.186 (-1.680)	0.677 (-0.390)	1.971 (0.678)	0.595 (-0.519)	1.260 (0.231)
Intersection density	4.940 (1.597)	0.044 (-3.131)	3.262 (1.182)	1.421 (0.351)	6.414 (1.858)	2.215 (9.161)	-4.269 (0.014)	1.175 (0.161)	0.907 (-0.097)	1.293 (0.257)	0.787 (-0.240)	1.083 (0.080)

(x): x refers coefficient
p<0.1 : *, p<0.05:**, p<0.01: ***

3) Characteristics of traffic accidents

With regard to the season, traffic accidents that occurred during autumn could have a high risk to increase injury accident of young elderly drivers and non-elderly drivers. The risk of injury accident was more than 50% higher in autumn than in spring, because the traffic volume in autumn is larger than in summer and winter. According to the traffic accident status from 2015 to 2017 from Koroad, traffic accidents occurred most frequently during the autumn season (October~November), and the highest number of casualties was observed during the autumn, which is consistent with the results of the present study (Joongang Ilbo 2018/10/18).

Winter season affected the injury severity of accidents committed by non-elderly drivers, while it reduced the occurrence of a serious injury accident, it increases injury accident. In contrast, the young elderly drivers group had a 50.79% increase in the likelihood of a fatal accident during winter rather than in spring. The increase in the risk of injury accident committed by non-elderly drivers and the number of fatal accidents committed by the young elderly drivers group were likely to increase due to the effects of heavy snow and road surface conditions. While these weather conditions are unlikely to cause an increase in serious injury accidents among by non-elderly drivers who were aware of road conditions and can react immediately during driving, the young-elderly drivers group was more likely to increase the possibility of the fatal accidents due to the difficulty of immediate response and physical aging. On the other hand, among the weather conditions, snowy days decreased the risk of injury accidents and fatal accidents by approximately 50% as compared with clear weather days. Similarly, the probability of fatal accidents in the three groups increased by about 50% in clear weather conditions as compared to foggy weather conditions.

The accident time (daytime and nighttime) also had a significant effect on the traffic accidents of the elderly driver groups as compared to the non-elderly drivers. Specifically, the risk of a serious injury accident and a fatal accident among young elderly drivers increased by over 50% at nighttime as compared to the daytime, and the probability of fatal accidents among middle- and old-elderly drivers rose by 50.5%. Traffic accidents on weekends, rather than on weekdays, were more likely to be fatal among middle- and old-elderly drivers, while the risk of serious injury accidents in the non-elderly drivers increased by 50%.

In the vehicle types, the injury severity has decreased when using a van, two-wheelers, and a prime mover rather than a passenger car. A van is a risk factor to increase severe accident severity of non-elderly drivers.

Among the accident types, pedestrian-vehicle accidents, as compared to car crashes, were by over 50% more likely to cause serious injuries and fatalities in all three groups.

Among the road types, the single road is associated with an increase of minor injury accidents among non-elderly drivers. The intersection increased the risk of a serious injury accident by 51%. In the young-elderly drivers group, road type had a significant effect, and the risk of fatal accident at an intersection increased by 50% as compared to a single road. It is consistent with the previous studies that traffic accidents involving elderly drivers at intersections is likely to lead to severe accidents(Oh et al., 2015; Choi, 2018b) The risk of a fatal accident in the young elderly drivers group was by 50% higher on a single road than on other types of roads.

In the case of a single road, the risk of an injury accident among middle- and old-elderly drivers increased by 52% compared to the others, which includes a tunnel, bridge, and underpass, whereas the others affected to increase possibility of minor injury accidents among middle and old-elderly drivers by 55%.

[Table 4-9] Result of marginal effect on features of the traffic accidents

	Odds ratio											
	Elderly drivers groups								Non-elderly drivers group			
	Young-elderly drivers				Middle- and Old-elderly drivers							
Variables	Injury accident	Minor injured accident	Serious injured accident	Fatal accident	Injury accident	Minor injured accident	Serious injured accident	Fatal accident	Injury accident	Minor injured accident	Serious injured accident	Fatal accident
Season (0:Spring)												
1. Summer	1.019 (0.019)	1.010 (0.010)	0.974 (-0.026)	0.997 (-0.003)	1.020 (0.020)	0.968 (-0.033)	1.003 (0.003)	1.010 (0.010)	1.008 (0.008)	0.9996 (-0.0004)	0.994 (-0.006)	0.999 (-0.002)
2. Autumn	1.048*** (0.047)	0.962 (-0.039)	0.981 (-0.019)	1.010*** (0.010)	1.012 (0.012)	0.991 (-0.009)	0.989 (-0.011)	1.008 (0.008)	1.019*** (0.019)	1.002 (0.002)	0.981 (-0.020)	0.999 (-0.001)
3. Winter	1.016 (0.016)	0.981 (-0.019)	0.972 (-0.028)	1.032*** (0.032)	1.023 (0.023)	0.973 (-0.027)	0.988 (-0.012)	1.017 (0.017)	1.011* (0.011)	1.008 (0.008)	0.982* (-0.018)	0.999 (-0.001)
Weekend (0: Week)	1.008 (0.008)	0.990 (-0.010)	0.997 (-0.003)	1.006 (0.006)	0.997 (-0.004)	0.989 (-0.011)	1.030 (0.029)	0.985* (-0.015)	1.007 (0.007)	0.973*** (-0.028)	1.021** (0.020)	1.001 (0.001)
Night time (0: Daytime)	0.992 (-0.008)	0.933*** (-0.070)	1.051* (0.050)	1.028*** (0.028)	1.009 (0.009)	0.973 (-0.028)	0.997 (-0.003)	1.022* (0.022)	0.998 (-0.002)	0.996 (-0.004)	1.004 (0.004)	1.003 (0.003)
Accident Type (0: Cars crash)												
1.Pedestrian -vehicle accident	1.008 (0.008)	0.788*** (-0.239)	1.205*** (0.187)	1.045*** (0.044)	0.976 (-0.024)	0.868*** (-0.142)	1.147*** (0.137)	1.029* (0.029)	0.993 (-0.007)	0.856*** (-0.155)	1.158*** (0.147)	1.016*** (0.016)
2. Single vehicle accident	1.0003 (0.0003)	0.887* (-0.120)	1.074 (0.071)	1.050 (0.048)	1.008 (0.008)	0.986 (-0.014)	0.934 (-0.068)	1.077 (0.074)	1.043*** (0.042)	0.912*** (-0.092)	1.044** (0.043)	1.007** (0.007)
Weather (0: Clear)												
1. Rain	1.029 (0.029)	0.963 (-0.037)	1.021 (0.021)	0.987 (-0.013)	1.004 (0.004)	0.960 (-0.041)	1.057 (0.055)	0.982*** (-0.018)	1.018 (0.018)	0.955** (-0.046)	1.024 (0.024)	1.004 (0.004)
2. Cloud	1.008 (0.008)	1.009 (0.009)	0.980 (-0.021)	1.004 (0.004)	0.967 (-0.033)	0.994 (-0.006)	1.049 (0.048)	0.991 (-0.009)	0.990 (-0.010)	0.975 (-0.026)	1.034** (0.034)	1.002 (0.002)
3. Snow	0.946*** (-0.056)	0.971 (-0.029)	1.110 (0.104)	0.981*** (-0.020)	0.916*** (-0.088)	1.125*** (0.118)	0.988 (-0.012)	0.982*** (-0.018)	0.933*** (-0.070)	0.810 (-0.211)	1.335 (0.289)	0.992*** (-0.008)
4. Fog	1.261 (0.232)	0.744 (-0.296)	1.087 (0.083)	0.981*** (-0.020)	0.916*** (-0.088)	0.967*** (-0.034)	1.150 (0.140)	0.982*** (-0.018)	1.088 (0.084)	0.947 (-0.054)	0.979 (-0.022)	0.992*** (-0.008)
5. etc									1.010 (0.010)	1.020 (0.020)	0.968 (-0.033)	1.003 (0.003)

(x): x refers coefficient
p<0.1 : *, p<0.05:**, p<0.01: ***

[Table 4-9] (Continued)

	Odds Ratio											
	Elderly drivers groups								Non-elderly drivers group			
	Young-elderly drivers				Middle- and Old-elderly drivers							
Variables	Injury accident	Minor injured accident	Serious injured accident	Fatal accident	Injury accident	Minor injured accident	Serious injured accident	Fatal accident	Injury accident	Minor injured accident	Serious injured accident	Fatal accident
Road Type (0: Single road)												
1: Intersection	0.982 (-0.018)	0.990 (-0.010)	1.014 (0.014)	1.014* (0.014)	0.990 (-0.011)	0.985 (-0.015)	1.036 (0.035)	0.990 (-0.010)	0.997 (-0.003)	0.977** (-0.023)	1.030*** (0.029)	0.997 (-0.003)
2: Others	1.096 (0.091)	0.994 (-0.006)	0.931 (-0.071)	0.987*** (-0.014)	0.912*** (-0.092)	1.211* (0.191)	0.868 (-0.142)	1.044 (0.043)	0.990 (-0.010)	1.020 (0.020)	0.991 (-0.009)	0.999 (-0.001)
Vehicle Type (0: Passenger Car)												
1: Van	0.968** (-0.032)	0.926 (-0.077)	1.083 (0.080)	1.030 (0.030)	1.039 (0.039)	0.849** (-0.163)	1.122 (0.115)	1.009 (0.009)	1.005 (0.005)	0.949*** (-0.052)	1.041*** (0.040)	1.006** (0.006)
2: two-wheeler	1.261*** (0.232)	0.762*** (-0.272)	1.058 (0.057)	0.984*** (-0.017)	1.254*** (0.227)	0.918 (-0.085)	0.798*** (-0.226)	1.088 (0.085)	1.170*** (0.157)	0.869*** (-0.141)	0.979 (-0.021)	1.005 (0.005)
3: Prime mover	1.513*** (0.414)	0.678*** (-0.388)	0.991 (-0.01)	0.984*** (-0.017)	1.204** (0.186)	0.871 (-0.138)	0.966 (-0.035)	0.987** (-0.013)	1.157*** (0.146)	0.822*** (-0.196)	1.039 (0.038)	1.012 (0.012)

(x): x refers coefficient
p<0.1 : *, p<0.05:**, p<0.01: ***

V. Conclusion

1. Summary and conclusion

The study aimed to examine the factors affecting injury severity of traffic accidents by elderly drivers in Seoul. To this end, the present study set elderly drivers into two groups by age: the young elderly drivers (aged 65 to under 70 years old) and the middle- and old-elderly drivers (70 years old and over) to analyze the factors affecting accidents severity of elderly drivers. To compare and analyze the accident characteristics of elderly drivers by accident severity, the research arranged a group of non-elderly drivers(aged 30 to under 65 years old) as a comparative group.

In Seoul, the elderly drivers' traffic accidents accounted for 10% of the total number of traffic accidents—i.e. the largest proportion in metropolitan cities of South Korea. Seoul has a high population density and various urban forms, so it is an appropriate site to study the influence of urban environment on traffic accidents.

The present study used the traffic accident data of Seoul in 2015, which were provided by the Korean National Police Agency. In the analysis, special vehicles and bicycles were excluded from the analyzed vehicle types; instead, it focused on the accidents that involved vans, passenger cars, two-wheelers, and prime movers. The number of traffic accident in the study included a total of 1,422 cases from the young elderly drivers group, 1,049 cases from the middle-and old-elderly drivers group, and 12,265 cases from the non-elderly drivers group. The variables used in the analysis were selected to account for the characteristics of

Seoul; it also considered previous studies on elderly drivers and the influence on them of urban environmental factors that may affect traffic accidents. The variables were categorized into demographic and socioeconomic indicators, urban environmental indicators, and features of the traffic accidents.

Since the dependent variable(accident severity) of the study had the sequence scale, the ordered logit model and the generalized ordered logit model, both of which are applicable when the dependent variable is discrete, were applied. However, the ordered logit model has the parallel assumption that the influence of the explanatory variable equally works in any dependent variable, even though the dependent variable has the ordinal form. Therefore, it was difficult to obtain estimators that would reflect heterogeneity in the estimation of single regression coefficients. In order to analyze the results of the ordered logit model, it was necessary to conduct a parallel line assumption test. As a result of the verification process, there was a problem that the results of the order logit model could be violated by rejecting the assumption. Therefore, the final results were derived from the generalized ordered logit model which relaxes the assumption that the value of the regression coefficient may be partially different according to the category.

The present study hypothesized that there would be differences in the factors affecting the number and severity of traffic accidents between non-elderly drivers and elderly drivers. The second hypothesis was that the effect of those factors would also differ between elderly and non-elderly drivers. Although there were common factors that affected all three groups, such as the ratio of detached houses, subway density, accident type, and vehicle type, significant differences in the accidents by injury severity and direction of influence were also observed in the results of analysis.

For example, the subway density was found to increase the incidence of injuries in the non-elderly drivers group, while the probability of fatal accidents in the young elderly drivers group increased. Furthermore, the bus stop density increased the probability of fatal accidents caused by the middle-and old-elderly drivers. This is because the use of public transportation increases the risk of exposure to vehicle-to-vehicle accidents, and the difficulty of securing visibility of elderly drivers due to bus-only roads and bus traffic affects traffic accidents (Jeong, 2015).

In addition, the research found several factors that have a significant influence on traffic accidents by elderly drivers, but not by non-elderly drivers. Transfer population ratio and traffic island density were found to be risk factors increased the probability of traffic accidents of elderly drivers. Traffic accidents occurring at night, compared to daytime, increased the risk(by 50%) of serious injury accidents and fatal accidents by young elderly drivers and fatal accidents among middle-and old-elderly drivers.

However, there were difference in the factors affecting in the elderly drivers groups. In particular, the effects of urban environment on traffic accidents was prominent in the middle-and old-elderly drivers group. Among the variables affecting accident severity of middle-and old-elderly drivers, the factors including household density, business density, and mixed land use, which were mainly represented high populated areas and traffic volume, increased the probability of accidents with severe injuries. This results is in a striking contrast from the case of traffic accidents by non-elderly drivers that the incidence of serious injury accident decreases in commercial area with a high traffic volume due to business and commercial facilities. It is in agreement with the results of previous studies(Lee et al., 2006; Lee et al., 2012) that traffic accident by elderly drivers increased in the areas with heavy traffic volume and complex environmental condition. It can be said that the complex environment include not only the road environment, but also the regional and spatial characteristics of an accident occurrence area. The characteristics of the middle-and old-elderly drivers—especially a decline in cognitive response time and physical aging—had a significant effect on the occurrence of minor injury and injury accident. In particular, detached house, which usually located with narrow road and frequent pedestrian traffic, and school zone, where mainly passed by pedestrians aged under 13 with absence of traffic safety increased the possibility of less serious injury accident.

In the some of related studies, the deteriorating weather condition, such as rain, snow, and fog, was a risk factor to increase injury severity and probability of traffic accident occurrence. However, in the present research, the results shows that it affected to reduce outbreak of accident, while the clear weather increase the possibility of accident occurrence by the both elderly drivers groups. In other words, elderly drivers are aware of the weather condition and its riskiness while driving.

The research also observed differences in the factors affecting the severity of accidents among elderly and non-elderly drivers. In the elderly driver groups, the hypothesis of the present study was confirmed, as the study found dissimilarity in the magnitude of the variables and the influences depending on elderly drivers' age.

In order to purpose relevant policy implication based on a profound understanding of the specific difficulties while driving, it is necessary to conduct an interview with elderly drivers. In the present research, the administrative district was set up as an analytical unit. In future studies, it would be necessary to narrow down the unit of analysis to better capture specific influence of urban spatial characteristics of accident site.

The contribution of the present study is that the study examined urban environmental factors that were not previously considered in the related studies. The present study also established the process of analyzing urban spatial and environmental characteristics that affect the accidents by elderly drivers in Seoul. The results of the resent study can be meaningfully used as basis of policy making to prevent elderly driver's traffic accident and enhancement of traffic safety policies targeting elderly drivers.

2. Consideration and Implications

The present study aimed to analyze the traffic accidents of urban elderly drivers from the perspective of urban planning; the second goal of the research was to examine the characteristics of traffic accidents by injury severity according to elderly drivers' age groups. Since the extant traffic accident researches have focused on road engineering, in the significance of the present study lies in that the study investigated accident severity among elderly drivers considering various urban environmental factors.

The result of this study is consistent with the previous studies(Lee, 2012; Jang et al., 2017) that elderly drivers are more susceptible to the negative impact of environmental conditions(traffic volume, road type, etc.). However, there is a difference in that the driving environment is not limited to the road infrastructure and road environmental factors, but also includes various factors of region. In particular, in the elderly drivers groups, the influence of the environmental factors was greater as the elderly driver's age increased. Since, in the middle- and old-elderly drivers group, various urban environmental variables, such as mixed land use, business density and bus stop density, influence the severity of traffic accidents. The result suggests that an adequate traffic safety policy would take into account urban environment characteristics, human factors, and road environmental factors.

With an increase in the number of pedestrian-vehicle accidents, accident severity, countermeasures for preventing accidents at the eye level of elderly drivers and a detailed follow-up study on them are necessary.

In order to solve the problem of the growing number of traffic accidents among elderly drivers, Japan and other advanced countries have studied the characteristics of elderly drivers and set relevant educational programs and the appropriate legal system (Park and Moon, 2012). By the contrast, the elderly driver's traffic policy in South Korea is the aptitude test conducted at the driver's license renewal, and other policies remain insufficient.

According to the "Actual Status of Elderly Driver Driving and Consciousness Survey" of the Road Traffic Authority, 51% of the respondents said that they would take a course for senior citizens, should such a course be provided. It emphasizes the need of various programs for elderly drivers. Therefore, it is a need to provide a variety of education programs by age in consideration of the fact that, as the age increases, the risk of severe accidents increases in complicated environments (e.g. high traffic volume and high accessibility of public transportation). In addition, it is necessary to improve social consciousness about the potential weaknesses of elderly drivers.

In Japan, the areas frequented by elderly drivers are designated, and appropriate measures, such as reduction of traffic volume, slowing down the driving speed, as well as aligning the signaling, road signs, walking facilities, are provided. Similarly, there are adequate measures that ensure mobility of elderly drivers that effectively prevent traffic accidents.

The factors that affect the occurrence of traffic accidents by elderly drivers are not limited to road factors and human factors. Therefore, it is necessary to introduce measures to prevent traffic accidents in each region considering, along with road and human factors, also the spatial characteristics of urban areas.

The present study demonstrated the effect of various factors including urban environment and regional characteristics on traffic accidents caused by elderly drivers. The results of present study emphasize that traffic safety and risk factors of traffic accidents are major planning factors that should be considered in urban planning. In view of the future changes in the urban space arising from social changes, it is necessary to continuously conduct traffic accident analysis of elderly drivers from the urban planning perspective.

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Appendix

1. Correlation analysis

1) Young-elderly drivers group

Variable(X)	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19	x20	x21	x22	x23	x24	x25	x26	x27	x28	x29	x30	x31
Season(x1)	1.00																														
Daytime, Nighttime(x2)	0.01	1.00																													
Week/Weekend(x3)	0.03	0.01	1.00																												
Accident type(x4)	0.02	0.08**	0.03	1.00																											
Weather(x5)	0.04	0.05	0.04	0.09**	1.00																										
Road type(x6)	0.02	0.07*	0.00	-0.09**	0.04	1.00																									
Vehicle type(x7)	-0.02	-0.06*	-0.01	0.08**	-0.02	0.00	1.00																								
Population density(x8)	0.00	0.03	0.05	0.01	0.01	0.05	0.06*	1.00																							
Household density(x9)	0.00	0.02	0.04	0.02	0.01	0.04	0.05*	0.97**	1.00																						
Male population ratio(x10)	-0.03	-0.01	-0.02	0.00	-0.04	0.01	0.05	-0.14**	-0.15**	1.00																					
Age over 64 ratio(x11)	0.02	-0.03	-0.04	0.04	0.00	-0.03	0.02	-0.33**	-0.29**	0.33**	1.00																				
Age under 20 ratio(x12)	0.02	0.00	0.03	0.01	0.04	0.02	-0.03	0.16**	0.04	-0.44**	-0.57**	1.00																			
Transfer population ratio(x13)	0.00	0.00	-0.02	0.01	-0.02	-0.04	0.01	-0.11**	0.02	0.15**	-0.08**	-0.26**	1.00																		
Basic livelihood recipients ratio(x14)	0.03	0.00	-0.01	0.04	-0.05	0.04	0.06*	-0.02	0.01	0.41**	0.54**	-0.42**	0.03	1.00																	
Employee density(x15)	-0.02	0.01	-0.05	-0.06*	0.02	-0.03	-0.05*	-0.31**	-0.28**	0.19**	0.28**	-0.49**	0.21**	0.06*	1.00																
Business density(x16)	-0.01	-0.01	-0.06*	-0.05	-0.01	-0.03	-0.01	-0.13**	-0.09**	0.45**	0.39**	-0.55**	0.23**	0.23**	0.70**	1.00															
School density(x17)	-0.01	0.02	0.00	0.00	-0.01	0.05	0.00	0.39**	0.36**	-0.05	-0.1**	0.11**	-0.12**	0.08**	-0.08**	0.06*	1.00														
University density(x18)	-0.03	-0.03	-0.03	-0.03	-0.04	-0.03	-0.01	-0.11**	-0.08**	0.06*	0.19**	-0.15**	0.09**	0.09**	0.06*	0.02	0.05	1.00													
Apartment ratio(x19)	0.04	0.01	0.00	0.01	0.02	0.01	-0.03	-0.11**	-0.19**	-0.03	-0.19**	0.45**	-0.09**	-0.08**	0.02	-0.08**	-0.03	-0.11**	1.00												
Detached house ratio(x20)	-0.04	-0.03	-0.04	-0.01	-0.02	-0.01	0.05	-0.10**	-0.05	0.28**	0.53**	-0.63**	-0.03	0.24**	0.22**	0.34**	0.06*	0.20**	-0.66**	1.00											
Residential area ratio(x21)	0.02	0.00	0.01	-0.01	-0.01	0.03	0.01	0.68**	0.66**	-0.22**	-0.32**	0.23**	-0.13**	-0.12**	-0.45**	-0.30**	0.30**	-0.09**	-0.12**	-0.12**	1.00										
Commercial area ratio(x22)	-0.01	0.01	-0.06*	-0.05	0.01	-0.05*	-0.04	-0.29**	-0.26**	0.24**	0.33**	-0.42**	0.16**	0.06*	0.74**	0.69**	-0.15**	-0.05*	0.11**	0.20**	-0.51**	1.00									
Industrial area ratio(x23)	-0.01	0.02	0.02	0.04	-0.01	0.00	0.01	-0.02	-0.02	0.18**	-0.19**	-0.08**	0.01	-0.08**	0.16**	0.07*	-0.07**	-0.06*	0.08**	-0.05*	-0.12**	-0.06*	1.00								
Green area ratio(x24)	-0.01	-0.01	0.04	0.05	0.00	0.01	0.02	-0.47**	-0.48**	-0.04	0.11**	0.16**	-0.01	0.1**	-0.24**	-0.33**	-0.17**	0.17**	0.00	-0.04	-0.59**	-0.34**	-0.13**	1.00							
Mixed land use(x25)	-0.05	0.03	0.02	-0.02	-0.03	0.04	-0.03	-0.29**	-0.29**	0.12**	-0.09**	0.09**	0.02	-0.05	-0.03	-0.10**	-0.15**	0.09**	0.25**	-0.22**	-0.36**	0.08**	0.30**	0.22**	1.00						
Road extension(x26)	-0.03	0.01	0.01	-0.04	0.06*	-0.01	-0.01	-0.12**	-0.12**	-0.08**	0.24**	-0.2**	-0.08**	0.07**	0.52**	0.20**	0.05	0.00	-0.05	0.20**	-0.24**	0.36**	-0.05*	-0.06*	-0.21**	1.00					
Bus stop density(x27)	-0.02	0.02	-0.03	-0.01	0.03	0.04	0.05	0.45**	0.46**	0.1**	0.17**	-0.19**	0.04	0.19**	0.15**	0.25**	0.29**	0.09**	-0.11**	0.15**	0.29**	0.08**	-0.08**	-0.37**	-0.13**	0.06*	1.00				
Subway density(x28)	0.01	0.02	-0.04	-0.06*	-0.02	-0.03	-0.01	0.12**	0.17**	0.11**	0.18**	-0.36**	0.2**	0.09**	0.48**	0.51**	0.10**	0.02	-0.06*	0.21**	-0.02	0.47**	-0.05	-0.4**	-0.14**	0.27**	0.33**	1.00			
School zone density(x29)	0.00	0.01	-0.02	0.00	0.02	0.02	0.00	0.61**	0.59**	-0.08**	-0.01	0.00	-0.15**	0.11**	-0.11**	0.02	0.33**	-0.05	-0.15**	0.11**	0.44**	-0.11**	-0.1**	-0.36**	-0.32**	0.01	0.39**	0.11**	1.00		
Intersection density(x30)	0.01	0.02	-0.05	-0.01	0.01	0.03	0.01	0.33**	0.35**	0.21**	0.12**	-0.26**	0.03	0.19**	0.36**	0.51**	0.25**	-0.06*	0.02	0.16**	0.16**	0.32**	0.09**	-0.5**	-0.1**	0.11**	0.55**	0.34**	0.36**	1.00	
Traffic island density(x31)	0.00	0.01	-0.01	-0.03	-0.03	0.03	-0.03	-0.06*	-0.03	0.27**	0.12**	-0.25**	0.10**	0.07**	0.33**	0.23**	0.01	-0.01	0.14**	0.06*	-0.02	0.27**	0.01	-0.22**	0.11**	0.07**	0.26**	0.17**	-0.02	0.43**	1.00

* $p < 0.05$

**. $p < 0.01$

1. Correlation analysis

2) Middle-and old-elderly drivers group

Variable(X)	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19	x20	x21	x22	x23	x24	x25	x26	x27	x28	x29	x30	x31
Season(x1)	1.00																														
Daytime, Nighttime(x2)	0.12**	1.00																													
Week/Weekend(x3)	-0.06	0.05	1.00																												
Accident type(x4)	0.04	0.05	0.02	1.00																											
Weather(x5)	0.08*	0.1**	0.05	0.03	1.00																										
Road type(x6)	-0.05	0.02	0.01	-0.208**	-0.04	1.00																									
Vehicle type(x7)	0.00	-0.11**	-0.01	-0.05	0.00	0.00	1.00																								
Population density(x8)	-0.02	0.00	0.05	0.02	-0.01	0.02	0.12**	1.00																							
Household density(x9)	-0.02	-0.01	0.06	0.03	-0.02	0.00	0.13**	0.97**	1.00																						
Male population ratio(x10)	-0.01	-0.01	-0.05	0.01	-0.02	0.01	0.00	-0.2**	-0.18**	1.00																					
Age over 64 ratio(x11)	-0.04	-0.01	0.02	0.03	0.00	-0.06	0.07*	-0.21**	-0.16**	0.35**	1.00																				
Age under 20 ratio(x12)	0.07*	0.01	-0.02	-0.03	0.01	0.08*	-0.03	0.11**	-0.05	-0.45**	-0.60**	1.00																			
Transfer population ratio(x13)	-0.03	-0.02	0.05	-0.05	-0.03	-0.03	-0.06	-0.12**	-0.02	0.17**	-0.04	-0.30**	1.00																		
Basic livelihood recipients ratio(x14)	0.00	-0.02	0.01	0.03	-0.01	-0.05	0.05	0.02	0.07**	0.47**	0.55**	-0.42**	0.04	1.00																	
Employee density(x15)	-0.05	0.00	-0.03	-0.02	0.02	-0.02	-0.06*	-0.28**	-0.23**	0.3**	0.23**	-0.47**	0.25**	0.07*	1.00																
Business density(x16)	-0.04	-0.02	-0.02	0.00	0.02	-0.05	0.01	-0.1**	-0.04	0.48**	0.38**	-0.54**	0.24**	0.25**	0.71**	1.00															
School density(x17)	0.03	-0.04	-0.02	0.03	0.03	0.01	0.10**	0.35**	0.32**	-0.04	-0.09**	0.11**	-0.14**	0.09**	-0.05	0.11**	1.00														
University density(x18)	-0.03	-0.01	0.03	0.05	0.04	-0.04	-0.02	-0.06*	-0.03	0.05	0.18**	-0.15**	0.01	0.06*	0.06	0.01	0.07*	1.00													
Apartment ratio(x19)	0.05	0.03	-0.07*	-0.04	-0.05	0.1**	-0.07*	-0.14**	-0.25**	0.00	-0.24**	0.52**	-0.15**	-0.16**	0.00	-0.12**	0.01	-0.13**	1.00												
Detached house ratio(x20)	-0.03	-0.01	0.03	0.02	0.04	-0.07*	0.09**	-0.03	0.06	0.27**	0.56**	-0.63**	0.03	0.33**	0.17**	0.34**	0.06*	0.22**	-0.68**	1.00											
Residential area ratio(x21)	-0.02	0.02	0.05	-0.01	0.02	0.00	0.10**	0.28**	0.68**	-0.28**	-0.24**	0.12**	-0.06*	-0.13**	-0.37**	-0.24**	0.25**	-0.08**	-0.14	-0.06	1.00										
Commercial area ratio(x22)	-0.02	-0.01	-0.05	-0.01	0.00	0.00	-0.09**	-0.28*	-0.25**	0.36**	0.32**	-0.43**	0.13**	0.11**	0.72**	0.68**	-0.07*	-0.05	0.08*	0.19**	-0.45*	1.00									
Industrial area ratio(x23)	-0.02	0.03	-0.06	-0.02	-0.01	-0.01	-0.03	-0.05	-0.05	0.19**	-0.18**	-0.06**	0.01	-0.07*	0.14**	0.04	-0.07*	-0.05	0.09**	-0.06	-0.13**	-0.04	1.00								
Green area ratio(x24)	0.05	-0.02	0.00	0.02	-0.02	-0.01	-0.03	-0.46**	-0.49**	-0.06*	0.04	0.25**	-0.05	0.07*	-0.26**	-0.34**	-0.18**	0.14**	0.06	-0.08**	-0.63**	-0.36**	-0.11**	1.00							
Mixed land use(x25)	0.00	-0.03	-0.05	0.01	-0.01	0.04	-0.12**	-0.36**	-0.36**	0.14**	-0.08**	0.05	-0.06*	-0.05	0.06	-0.07*	-0.12**	0.07*	0.26**	-0.20**	-0.42**	0.19**	0.31**	0.2**	1.00						
Road extension(x26)	-0.03	0.01	00	-0.02	0.02	0.02	-0.04	-0.04	-0.05	-0.06	0.13**	-0.06*	-0.09**	0.01**	0.37**	0.14**	0.08*	0.02	0.02	0.09**	-0.16**	0.24**	-0.02	-0.03	-0.1**	1.00					
Bus stop density(x27)	-0.02	0.03	0.05	0.03	0.02	-0.03	0.05	0.47**	0.49**	0.11**	0.21**	-0.21**	0.03	0.26**	0.18**	0.25**	0.27**	0.09**	-0.13**	0.18**	0.30**	0.08**	-0.08*	-0.36**	-0.13**	0.09**	1.00				
Subway density(x28)	-0.05	0.00	0.02	-0.01	-0.02	-0.03	0.05	0.17**	0.22**	0.13**	0.15**	-0.37**	0.21**	0.07*	0.46**	0.49**	0.13**	0.05	-0.07*	0.18**	0.06	0.40**	-0.07*	-0.38**	-0.11**	0.17**	0.26**	1.00			
School zone density(x29)	0.00	-0.02	0.03	0.03	-0.02	0.00	0.12**	0.62**	0.61**	-0.08**	0.04	-0.03	-0.15**	0.14**	-0.10**	0.04	0.33**	0.04	-0.17**	0.13**	0.43**	-0.11**	-0.11**	-0.34**	-0.32**	0.01	0.40**	0.15**	1.00		
Intersection density(x30)	-0.02	0.02	0.04	-0.04	0.00	0.04	0.06	0.36**	0.38**	0.27**	0.15**	-0.27**	0.06*	0.25**	0.37**	0.50**	0.34**	-0.08*	0.01	0.17**	0.19**	0.32**	0.07*	-0.49**	-0.09**	0.13**	0.56**	0.31**	0.32**	1.00	
Traffic island density(x31)	-0.08*	0.04	0.01	0.00	0.01	0.07*	-0.02	-0.08*	-0.04	0.40**	0.14**	-0.27**	0.18**	0.13**	0.35**	0.25**	0.00	-0.06	0.14**	0.04	-0.01	0.32**	0.01	-0.26**	0.11**	0.01	0.23**	0.18**	-0.02	0.44**	1.00

* p 〈 0.05

**. p 〈0.01

1. Correlation analysis

3) Non-elderly drivers group

Variable(X)	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19	x20	x21	x22	x23	x24	x25	x26	x27	x28	x29	x30	x31
Season(x1)	1.00																														
Daytime, Nighttime(x2)	0.04**	1.00																													
Week/Weekend(x3)	0.02	0.06**	1.00																												
Accident type(x4)	0.01	-0.02*	-0.01	1.00																											
Weather(x5)	0.05**	0.09**	0.03**	.02*	1.00																										
Road type(x6)	-0.01	0.02	-0.02	-0.14**	0.01	1.00																									
Vehicle type(x7)	-0.02*	-0.10**	-0.04**	0.14**	-0.03**	-0.01	1.00																								
Population density(x8)	0.00	0.01	0.01	0.02	0.02	0.03**	0.03**	1.00																							
Household density(x9)	0.00	0.02	0.01	.021*	0.01	0.03**	0.04**	0.96**	1.00																						
Male population ratio(x10)	-0.01	-0.01	-.024**	0.02*	0.00	0.00	.045**	-0.12**	-0.14**	1.00																					
Age over 64 ratio(x11)	0.00	-0.02*	-0.01	0.06**	-0.02*	-0.02*	0.07**	-0.25**	-0.20**	0.32**	1.00																				
Age under 20 ratio(x12)	0.00	-0.02*	0.01	-0.04**	0.02*	0.01	-.06**	0.16**	-0.04**	-.40**	-0.54**	1.00																			
Transfer population ratio(x13)	0.01	0.01	-0.02*	-0.01	0.00	0.00	-0.01	-.13**	-0.01	0.06**	-.10**	-0.24**	1.00																		
Basic livelihood recipients ratio(x14)	-0.01	-0.01	-0.01	0.05**	-0.02*	0.00	0.05**	-0.06**	-0.02*	0.53**	0.61**	-0.48**	0.03**	1.00																	
Employee density(x15)	0.01	-0.01	-0.04**	0.00	-0.01	0.00	0.01	-0.25**	-0.20**	0.20**	0.20**	-0.44**	0.24**	0.14**	1.00																
Business density(x16)	0.00	-0.01	-0.03**	0.01	-0.01	0.00	0.06**	0.09**	0.11**	0.35**	0.31**	-0.39**	0.09**	0.25**	0.48**	1.00															
School density(x17)	0.00	0.00	-0.01	0.01	0.01	0.04**	0.03**	0.47**	0.45**	-007**	-0.03**	-0.05**	-0.06**	-0.02	-0.03**	0.19**	1.00														
University density(x18)	0.00	-0.01	0.00	0.02*	-0.01	-.023*	0.01	-0.08**	-0.05**	0.01	0.12**	-0.10**	0.04**	0.14**	0.05**	-0.05**	0.08**	1.00													
Apartment ratio(x19)	0.00	0.01	-0.01	-0.04**	0.00	0.03**	-0.01	-0.02*	-0.05**	-0.05**	0.02*	0.16**	-0.17**	0.02*	0.06**	0.02*	0.14**	-0.06**	1.00												
Detached house ratio(x20)	0.00	0.00	0.00	0.04**	-0.01	0.00	0.03**	0.04**	0.07**	0.08**	0.04**	-0.21**	0.13**	0.05**	-0.04**	0.03**	-0.10**	0.05**	-0.68**	1.00											
Residential area ratio(x21)	0.00	0.03**	0.02*	0.00	0.01	0.00	0.00	0.69**	0.68**	-0.22**	-0.25**	0.15**	-0.09**	-0.16**	-0.34**	-0.09**	0.27**	-0.09**	0.00	-0.01	1.00										
Commercial area ratio(x22)	0.02	-0.01	-0.03**	-0.01	0.00	0.02	0.03**	-0.24**	-0.22**	0.26**	0.29**	-0.39**	0.16**	0.16**	0.72**	0.54**	-0.05**	-0.07**	0.13**	-0.07**	-0.41**	1.00									
Industrial area ratio(x23)	-0.02*	0.02*	-0.01	-0.02	0.00	0.01	0.01	-0.05**	-0.04**	0.23**	-0.17**	-0.10**	-0.01	-0.05**	0.15**	-0.01	-0.08**	-0.06**	0.05**	0.03**	-0.15**	-0.05**	1.00								
Green area ratio(x24)	-0.01	-0.03**	0.01	0.01	-0.02	-0.02*	-0.02**	-0.50**	-0.51**	-0.05**	0.08**	0.19**	-0.03**	0.05**	-0.28**	-0.33**	-0.22**	0.17**	-0.12**	0.06**	-0.65**	-0.36**	-0.13**	1.00							
Mixed land use(x25)	0.01	0.01	0.01	-.02	-0.01	0.00	-0.03**	-0.33**	-0.31**	0.11**	-0.07**	0.02**	-0.02*	-0.03**	0.04**	-0.20**	-0.20**	0.05**	-0.03**	0.07**	-0.41**	0.18**	0.33**	0.17**	1.00						
Road extension(x26)	0.00	0.01	0.00	0.00	-0.01	-0.02	0.00	-0.10**	-0.09**	0.18**	0.18**	-0.12**	0.09**	0.18**	0.12**	-0.04**	-0.03**	0.20**	0.04**	-0.10**	-0.07**	0.02	-0.04**	0.07**	0.05**	1.00					
Bus stop density(x27)	0.01	0.00	-0.02	0.04**	-0.02*	0.00	0.06**	0.45**	0.47**	0.13**	0.19**	-0.21**	0.01	0.23**	0.20**	0.26**	0.27**	0.08**	-0.06**	0.04**	0.28**	.0.08**	0.06**	-0.37**	-0.12**	0.08**	1.00				
Subway density(x28)	0.01	0.01	-0.02	-0.01	-0.01	0.00	0.03**	0.17**	0.21**	0.08**	0.12**	-0.28**	0.20**	0.11**	0.46**	0.47**	0.22**	0.00	0.08**	-0.06**	0.07**	0.43**	-0.08**	-0.39**	-0.09**	0.03**	0.30**	1.00			
School zone density(x29)	-0.01	-0.01	0.00	0.03**	0.00	0.02*	0.04**	0.61**	0.59**	-0.05**	0.04**	-0.02*	-0.17**	0.09**	-0.10**	0.20**	0.33**	-0.06**	-0.02*	0.06**	0.45**	-0.08**	-0.10**	-0.36**	-0.31**	-0.04**	0.39**	0.15**	1.00		
Intersection density(x30)	0.02	0.00	-0.02*	0.02*	0.00	0.03**	0.06**	0.40**	0.41**	0.19**	0.12**	-0.19**	-0.01	0.22**	0.34**	0.43**	0.22**	-0.03**	0.09**	-0.06**	0.26**	0.27**	0.06**	-0.50**	-0.12**	-0.02*	0.57**	0.32**	0.39**	1.00	
Traffic island density(x31)	0.01	0.00	-0.01	0.02*	0.01	0.01	0.03**	-0.02	0.01	0.26**	0.11**	-0.21**	0.08**	0.13**	0.31**	0.11**	0.04**	-0.02*	0.03**	-0.01	0.02	0.27**	0.00	-0.23**	0.09**	-0.01	0.23**	0.15**	0.00	0.40**	1.00

* p 〈 0.05

**. p 〈0.01

2. Basic statistical analysis

1) Young-elderly drivers group (N=1,422)

Explanatory variables	Mean	Standard Deviation	Min.	Max.
Household density	7.77	4.58	0.16	23.57
Male population ratio	0.5	0.03	0.44	0.63
Age over 64 population ratio	0.13	0.03	0.07	0.24
Age under 20 population ratio	0.16	0.04	0.06	0.3
Transfer population ratio	0.16	0.04	0.07	0.41
Basic livelihood recipients ratio	0.02	0.02	0.0002	0.18
Business density	2.65	2.9	0.05	22.98
School density	0.002	0.002	0	0.01
University density	0.0002	0.0005	0	0.004
Apartment ratio	0.55	0.28	0	1
Detached house ratio	0.17	0.15	0	0.89
Residential area ratio	0.57	0.25	0.02	0.99
Commercial area ratio	0.18	0.21	0	0.95
Industrial area ratio	0.02	0.07	0	0.66
Mixed land use	0.51	0.17	0.0003	0.97
Road extension	1.49	3.39	0.001	22.01
Bus stop density	0.02	0.01	0.002	0.09
Subway density	0.001	0.001	0	0.01
School zone density	0.003	0.002	0	0.01
Traffic island density	0.004	0.004	0	0.02
Intersection density	0.01	0.01	0	0.05
Season(0:Spring)				
1. Summer	0.23	0.42	0	1
2. Autumn	0.28	0.45	0	1
3. Winter	0.23	0.42	0	1
Date(0:Week)				
1. Weekend	0.25	0.43	0	1
Time(0:Daytime)				
1. Night time	0.43	0.5	0	1
Accident type(0:Cars crash)				
1. Pedestrian-vehicle	0.25	0.43	0	1
2. Single vehicle accident	0.04	0.2	0	1
Weather(0:Clear)				
1. Rain	0.04	0.19	0	1
2. Cloud	0.08	0.27	0	1
3. Snow	0.003	0.05	0	1
4. Fog	0.005	0.27	0	1
Vehicle type(0: Passenger car)				
1. Van	0.08	0.27	0	1
2. Two-wheeler	0.03	0.17	0	1
3. Prime mover	0.02	0.13	0	1
Road type(0: Single road)				
1. Intersection	0.43	0.49	0	1
2. Others	0.03	0.16	0	1

2) Middle-and old-elderly drivers group (N=1,049)

Explanatory variables	Mean	Standard Deviation	Min.	Max.
Household density	7.7	4.34	0.16	23.57
Male population ratio	0.5	0.03	0.44	0.63
Age over 64 population ratio	0.13	0.03	0.07	0.23
Age under 20 population ratio	0.17	0.04	0.06	0.3
Transfer population ratio	0.16	0.04	0.07	0.71
Basic livelihood recipients ratio	0.02	0.02	0.0002	0.18
Business density	2.48	2.78	0.05	22.98
School density	0.002	0.002	0	0.01
University density	0.0001	0.0005	0	0.004
Apartment ratio	0.57	0.29	0	1
Detached house ratio	0.16	0.14	0	0.89
Residential area ratio	0.59	0.24	0.02	0.99
Commercial area ratio	0.17	0.19	0	0.95
Industrial area ratio	0.02	0.07	0	0.66
Mixed land use	0.51	0.17	0.04	0.97
Road extension	1.24	2.79	0.002	22.01
Bus stop density	0.02	0.01	0.001	0.09
Subway density	0.001	0.001	0	0.01
School zone density	0.003	0.002	0	0.01
Traffic island density	0.004	0.004	0	0.02
Intersection density	0.01	0.01	0	0.05
Season(0:Spring)				
1. Summer	0.25	0.43	0	1
2. Autumn	0.27	0.45	0	1
3. Winter	0.25	0.43	0	1
Date(0:Week)				
1. Weekend	0.25	0.43	0	1
Time(0:Daytime)				
1. Night time	0.36	0.48	0	1
Accident type(0:Cars crash)				
1. Pedestrian-vehicle	0.29	0.46	0	1
2. Single vehicle accident	0.03	0.16	0	1
Weather(0:Clear)				
1. Rain	0.04	0.2	0	1
2. Cloud	0.07	0.25	0	1
3. Snow	0.003	0.05	0	1
4. Fog	0.01	0.08	0	1
Vehicle type(0: Passenger car)				
1. Van	0.05	0.21	0	1
2. Two-wheeler	0.05	0.21	0	1
3. Prime mover	0.03	0.17	0	1
Road type(0: Single road)				
1. Intersection	0.42	0.49	0	1
2. Others	0.02	0.13	0	1

3) Non-elderly drivers group (N=12,265)

Explanatory variables	Mean	Standard Deviation	Min.	Max.
Household density	7.86	4.41	0.16	23.57
Male population ratio	0.49	0.03	0.44	0.63
Age over 64 population ratio	0.13	0.03	0.07	0.23
Age under 20 population ratio	0.16	0.05	0.06	0.3
Transfer population ratio	0.16	0.04	0.07	0.71
Basic livelihood recipients ratio	0.02	0.02	0.0002	0.18
Business density	2.57	3.96	0.05	22.98
School density	0.003	0.003	0	0.01
University density	0.0001	0.0004	0	0.004
Apartment ratio	0.55	0.3	0	1
Detached house ratio	0.16	0.14	0	0.89
Residential area ratio	0.59	0.24	0.02	0.99
Commercial area ratio	0.17	0.19	0	0.95
Industrial area ratio	0.02	0.08	0	0.66
Mixed land use	0.52	0.17	0.04	0.97
Road extension	22.99	71.5	0.002	22.01
Bus stop density	0.02	0.01	0.001	0.09
Subway density	0.001	0.001	0	0.01
School zone density	0.003	0.002	0	0.01
Traffic island density	0.003	0.004	0	0.02
Intersection density	0.01	0.01	0	0.05
Season(0:Spring)				
1. Summer	0.24	0.23	0	1
2. Autumn	0.18	0.38	0	1
3. Winter	0.32	0.47	0	1
Date(0:Week)				
1. Weekend	0.27	0.44	0	1
Time(0:Daytime)				
1. Night time	0.52	0.5	0	1
Accident type(0:Cars crash)				
1. Pedestrian-vehicle	0.22	0.42	0	1
2. Single vehicle accident	0.06	0.24	0	1
Weather(0:Clear)				
1. Rain	0.04	0.2	0	1
2. Cloud	0.08	0.28	0	1
3. Snow	0.0002	0.02	0	1
4. Fog	0.003	0.05	0	1
5. Etc	0.01	0.09	0	1
Vehicle type(0: Passenger car)				
1. Van	0.11	0.31	0	1
2. Two-wheeler	0.08	0.28	0	1
3. Prime mover	0.01	0.09	0	1
Road type(0: Single road)				
1. Intersection	0.41	0.49	0	1
2. Others	0.02	0.16	0	1

국문 초록

도시 고령 운전자의 교통사고 특성

- 일반화된 순서형 로짓 모형 적용 -

이지원
환경계획학과 도시 및 지역 계획학 전공
서울대학교 환경대학원

도시민의 겪는 사회 재난 중 하나인 교통사고는 급속도로 고령화가 진행됨에 따라 고령 운전자에 의한 교통사고 발생이 날로 증가하고 있다. 고령 운전자는 인적 요인(신체적·정신적 노화, 심리 상태)이 교통사고 발생에 큰 영향을 미치며, 비 고령 운전자에 비하여 주행 중 주변 환경의 영향을 많이 받는다. 따라서 교통사고가 발생했을 때 심각한 인명피해로 이어질 가능성이 높다. 이처럼 고령 운전자는 비 고령 운전자와 다른 양상을 보임에도 불구하고, 고령 운전자의 특징과 다양한 요인을 고려한 연구보다는 도로 공학 중심의 연구가 진행되어 왔다. 고령자의 이동성을 보장하고 안전한 도시를 조성하기 위해서는 도시 환경을 포함한 주행 중 영향을 미칠 수 있는 다양한 요인들을 고려해야 하며, 도시 계획적 접근 방식의 연구가 필요하다.

위와 같은 배경에서 본 연구는 서울시에서 발생한 고령 운전자의 교통사고를 대상으로 사고 심각도 별 교통사고 발생에 영향을 미치는 요인을 파악하고자 하였다. 본 연구에서는 고령 운전자를 연령에 따라 초기 고령 운전자(65세 이상 70세 미만), 중·후기 고령 운전자(70세 이상)로 구분하여 연령별 교통사고 발생에 영향을 미치는 요인을 분석하고자 하였다. 또한 비 고령 운전자(30세 이상 65세 미만)를 비교 집단으로 선정하여 고령 운전자의 교

통사고 심각도 별 사고 특성을 면밀히 파악하고자 하였다.

고령 운전자의 교통사고 심각도 별 사고 특성과 비 고령 운전자의 교통사고 심각도 별 특성이 다르게 나타날 것으로 가설을 세웠으며, 고령 운전자 집단 내에서도 사고 심각도 별 교통사고 발생에 영향을 미치는 요인이 연령에 따라 다르게 나타날 것으로 예측하였다. 또한 고령 운전자의 교통사고 특성을 분석하기 위하여 고령 운전자의 인적 특성과 교통사고 특성, 도시 환경과 교통에 관한 선행연구를 고찰하였다. 이 후 선행 연구 고찰 내용과 연구대상 지역인 서울시의 특성을 고려하여 고령 운전자의 교통사고에 영향을 미칠 것으로 예측되는 인구 및 사회경제학적 요인, 도시 환경 요인, 교통사고 특성을 반영하는 변수들을 선정하였고, 분석에 필요한 데이터를 구축하였다.

본 연구에서는 종속변수가 순서화된 형태로 분포할 경우 사용하기 적합한 순서형 로짓 모형을 1차 분석 모형으로 이용하였다. 순서형 로짓 모형은 종속변수가 순서화된 형태를 보이더라도 설명변수 x의 영향력이 어떠한 종속변수의 범주에서도 달라지지 않는다는 평행선 가정을 충족시켜야 한다. 만일 평행선 가정을 충족시키지 못하는 경우, 분석 결과를 오역할 수 있다는 한계점을 갖는다. 따라서 본 연구에서는 순서형 로짓 모형 분석 결과가 평행선 가정을 충족하지 못하는 경우를 대비하여 범주에 따라 회귀 계수의 크기가 부분적으로 다를 수 있도록 가정을 완화한 일반화된 순서형 로짓 모형을 2차 분석 모형으로 설정하였다.

순서형 로짓 모형 분석 결과, 평행선 검증의 귀무가설을 기각하여, 분석 결과를 오역할 수 있다는 한계점이 나타났다. 따라서 2차 분석 모형(일반화된 순서형 로짓 모형)을 이용하여 최종적인 교통사고 심각도 별 사고 특성 모형을 개발하였다. 일반화된 순서형 로짓 모형 분석 결과, 운전자 연령 집단에 따라 사고 심각도 별 교통사고 발생에 영향을 미치는 요인은 유의미한 차이가 있었다. 특히 고령 운전자(만 65세 이상)와 비 고령 운전자(만 30세 이상 65세 미만)의 교통사고 심각도 별 사고 발생에 영향을 미치는 요인에는 유의미한 차이가 있음을 확인하였으며, 동일한 요인이 교통사고 발생에 영향을 미치더라도 영향의 방향과 크기, 그리고 영향을 받는 교통사고 심각도가 다르게 나타났다. 예를 들어, 대중교통접근성(지하철 밀도, 버스 정류장

밀도)은 세 집단의 교통사고 발생에 정(+)의 영향을 미친다. 그러나 비 고령 운전자 집단에서는 지하철 밀도가 사고 심각도가 낮은 부상 신고 사고 발생 가능성을 증가시키는 반면, 초기 고령 운전자 집단에서는 사고 심각도가 높은 사망사고 발생 가능성을 증가시키는 것으로 나타났다. 중·후기 고령 운전자 집단에서는 지하철 밀도보다는 버스 정류장 밀도가 사고 심각도가 높은 사망사고 발생 가능성을 증가시키는 변수로 나타났다. 이처럼 대중교통접근성은 본 연구에서 예측했던 바와 같이 교통사고에 대한 노출 위험을 증가시키는 요소로 나타났다. 이는 대중교통을 이용하기 위한 보행자 통행 증가 및 버스 통행량 증가와 버스전용차선이 고령 운전자의 시야 확보에 악영향을 미쳐 사고 심각도가 높은 교통사고 발생 가능성이 증가한 것으로 볼 수 있다.

또한 고령 운전자의 교통사고 특성 분석 결과를 통해서 고령자의 신체적 노화 현상이 교통사고에 미치는 영향을 확인할 수 있었다. 대형 교차로에 설치되며 진입구간에서 차로 폭이 좁아져 교통사고가 빈번히 발생하는 교통섬에서 고령 운전자의 중상사고 발생 가능성은 증가하였다. 또한 시야 확보가 어려운 야간 주행의 경우, 주간에 발생하는 교통사고보다 중상사고(초기 고령운전자)와 사망사고(초기 고령 운전자와 중·후기 고령운전자)로 이어질 가능성이 50% 높게 나타났다.

고령 운전자 집단에서도 연령이 높은 중·후기 고령운전자 집단의 교통사고 발생에 도시환경이 미치는 영향이 두드러졌다. 중·후기 고령 운전자 집단의 중상사고와 사망사고 발생 가능성을 증가시키는 요인들은 가구밀도, 사업체 밀도, 혼합 토지 이용이며, 이들은 주로 인구밀도가 높고 인구 유입을 유도하며, 통행량이 많은 지역이라는 특징을 갖는다. 즉, 고령 운전자가 주행 중 복잡하다고 느낄만한 요소들이 충분한 환경이라고 볼 수 있다. 위와 같은 결과는 업무 및 상업시설 이용을 위하여 통행량이 많은 상업지역 비율이 높은 곳에서 오히려 중상사고 발생 가능성이 감소한 비고령 운전자와 대조적이다. 또한 중·후기 고령 운전자의 교통사고(부상신고사고, 경상사고)는 단독주택 비율과 어린이보호구역 밀도와 같이 보행자의 통행이 주로 이루어지며, 교통안전의식이 낮은 어린이 통행이 잦은 지역에서 사고 발생 가능성이 증가하였다. 이는 주행 중 사각지대에 위치한 보행자를 인지하지 못하거나(가용 시각

장 감소, 청력 감소), 보행자의 돌발 행동에 즉각적으로 대응하지 못하여(인지반응속도저하) 고령 운전자의 사고 심각도가 낮은 교통사고 발생 가능성이 증가한 것으로 보인다.

본 연구를 통해서 고령 운전자와 비 고령 운전자의 교통사고 심각도 별 사고 발생에 영향을 미치는 요인은 차이가 있으며, 고령 운전자 집단에서도 연령에 따라 영향 요인과 영향의 크기에 유의미한 차이가 있음을 확인하여 연구 가설을 입증하였다. 또한 고령 운전자의 교통사고에 영향을 미치는 주행 환경은 도로 환경 요소(교차로, 교통섬, 차로 수 등)만을 포함하는 것이 아니라 도시의 공간적 특성을 함께 포함한다는 것을 확인하였다.

본 연구는 도시 공간적 요소를 포함한 다양한 요소들이 고령 운전자의 교통사고 발생에 미치는 영향을 증명하였다. 고령자의 이동성을 보장하고 고령 운전자의 교통사고를 효과적으로 방지하기 위해서는 고령 운전자의 특성과 도시의 공간적 특성을 고려하여 사고 다발 지역에 대한 물리적 환경 개선과 정책 마련이 필요하다. 또한, 이를 반영한 다양한 교통안전 교육 프로그램 개발과 더불어 고령 운전자를 이해하고 배려할 수 있도록 사회적 의식 개선이 함께 이루어져야 할 것이다.

주요어 : 고령 운전자, 고령화, 교통사고, 교통사고 심각도, 일반화된 순서형 로짓 모형

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