Impact of the Silver Zone on the Traffic Accident Rate of Elderly Pedestrians

By

CHO, Hee Young

THESIS

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

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Committee in charge:

Professor Kim, Joeun, Supervisor

Professor Lee, Changkeun

Professor Park, Jinseong

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Abstract

Impact of the Silver Zone on the Traffic Accident Rate of Elderly Pedestrians in South Korea

Background**:** To reduce elderly pedestrian traffic accidents, the South Korean government introduced the "Silver Zone" (Elderly Protection Area) program in 2007. Multiple measures such as lowering speed limits, zone-designation signs, installing speed bumps, unmanned cameras, or elevated crosswalks are permitted within the area.

Methods: In this study, panel data with 16,633 observations by the district "Dong" (the smallest administrative district unit in South Korea) was created and analyzed by using Stata-17. With the data, fixed effect regression analysis has been performed to identify the impact of the Silver Zone installed in Seoul city from 2007 to 2022 on three kinds of traffic accident data- death rate, severe injury rate, and accident rate. This study also applied the interaction effect method to examine how the impact of the Silver Zone differs by gender.

Findings: The installation of the Silver Zone is associated with a reduction in severe injury rate and traffic accident rate of elderly pedestrians, but it did not display statistically significant results for the death rate. Additionally, contrary to the hypothesis, the Silver Zone is less likely to be effective in reducing the traffic accidents of female elderly pedestrians who are the most prominently vulnerable population to traffic accidents, which raises necessity for the policy improvement.

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I. Introduction

1-1. Introduction

Across high-income countries, population aging is occurring rapidly. This trend is particularly pronounced in South Korea, where life expectancy has increased, and fertility rates are exceptionally low (OECD, 2024). Currently, nearly 16.6% of the population is elderly, aged 65 and older, with expectations to reach nearly 20% in 2025 (Korea National Statistics Office, 2021). Such demographic shifts toward aging have drawn significant public and scholarly attention to health concerns among the older population.

To date, numerous studies have focused on the mental and physical health issues among the elderly, largely overlooking the potential role of traffic accidents. This oversight is significant, given that the elderly population is at a considerable risk of being victims of traffic accidents, as walking is a common means of transportation for them (Ghani et al., 2016). Statistics comparing with younger populations would illustrate this risk more concretely (Korea Ministry of Interior and Safety, 2023).

Recognizing the importance of traffic safety, the South Korean government introduced the “Silver Zone" in 2007 (KTV, 2007), designated areas where speed limits are reduced to protect the elderly population. However, empirical evidence on the effectiveness of such measures remains mixed and limited. Some studies have reported positive outcomes (Lee, 2012), while others have not (Choi, Yoon & Jeong, 2018; Ahn, 2015). This inconsistency underscores the necessity of more comprehensive evaluations, preferably through longitudinal studies, to ascertain the effectiveness of the "Silver Zones" in enhancing road safety for the elderly.

In this study, using elderly pedestrian traffic accident data from 2007 to 2022, I examine whether the installation of Silver Zone has contributed to reducing elderly pedestrian traffic accidents. Also, I additionally test whether such intervention has varying impacts by gender.

1-2. Research Questions

First, this study will determine the impact of the Silver Zone by responding to the questions below.

Q1.1 Did the Silver Zone reduce elderly pedestrians' road traffic collision rate?
Q1.2 Did the Silver Zone reduce elderly pedestrians' injury rate?
Q1.3 Did the Silver Zone reduce elderly pedestrians' death rate?

Second, this study aims to observe the impact of the Silver Zone by gender and discover whether the Silver Zone has benefitted the female elderly, who are the primary victims of pedestrian traffic accidents.

Q2. Is the impact of the Silver Zone more salient for elderly females?

II. Literature Review

2-1. Elderly Pedestrian Traffic Accident

According to the statistics of Korea Road Traffic Authority (2022), the proportion of elderly among overall traffic accident deaths in 2022 was 46.0% - 1,258 out of 2,735 of the total traffic accident fatalities.

When it comes to pedestrian-vehicle collisions, this trend is more obviously observed as the proportion of elderly among pedestrian deaths is 59.8% in 2022, and 558 out of 933 pedestrian deaths were elderly.

Table 1 Number of Pedestrian Deaths by Year (Koroads, 2022)

year	Death (Korea)		
	65 and older	whole age	% of 65+
2007	985	2304	42.8%
2008	903	2137	42.3%
2009	952	2137	44.5%
2010	966	2082	46.4%
2011	883	2044	43.2%
2012	959	2027	47.3%
2013	951	1982	48.0%
2014	919	1910	48.1%
2015	909	1795	50.6%
2016	866	1714	50.5%
2017	906	1675	54.1%
2018	842	1487	56.6%
2019	743	1302	57.1%
2020	628	1093	57.5%
2021	601	1018	59.0%
2022	558	933	59.8%

2-2. The Behavioral Pattern of the Elderly in Traffic Versus the Non-elderly, and the Gender Effect

Compared to the child as a vulnerable population for traffic accidents, elderly pedestrians received less attention from academia before the 2000s, but scholars started to show interest in the impact of aging on pedestrians and their street-crossing situations in the 2000s along with the aging population situation of each country and only a few of them dealt with gender effect.

Coffin and Morall (1995) observed that elderly pedestrians had difficulty related to crossing the street in various kind of situations such as judging the speed of incoming vehicles, confusing road signs in a wrong way (i.e. “Walk” to “Do not Walk”)

Lobjois and Cavallo (2007) conducted experiments in 3D virtual settings to identify the impact of both aging and gender in street-crossing situations by creating vehicle-crossing situations and measuring the crossing time of participants divided into three age groups.

They found out that the elderly are more vulnerable in complex traffic situations with higher vehicle speeds than the non-elderly. When it comes to gender effect, there was no difference between young men and women but a significant difference between elderly men and women in time constraint situations.

Meanwhile, Visby and Lundholt (2018) focused on the gender differences in travel patterns and traffic accidents by analyzing traffic accidents and travel survey data conducted from 2009 to 2012. According to them, men drive more and take longer trips, while women prefer walking and riding bicycles and drive shorter distances.

Also, South Korean scholars studied contrasting characteristics of walking patterns between elderly and non-elderly, but a very limited number of studies paid attention to the gender effect on elderly pedestrian issues.

Han et al. (2020) identified aging and gender effects on walking speed by analyzing actual pedestrian crossing speed. According to their study, the walking speed of the general public is 1.29 m/s, while that of the average elderly was 1.13 m/s, 0.16 m/s slower than the overall age group. Meanwhile, the walking speed of the lower 15th percentile elderly was 0.85m/s, while that of the general public was 1.01m/s.

But the speed of the lower 15th of the elderly using sticks or wheelchairs gets lower to 0.73m/s, below the standard speed (0.8m/s) to set pedestrian signals in Silver Zone.

They observed the gender difference in walking speed. While overall men's walking speed was 1.31 m/s, that of women was 1.28 m/s, 0.03m/s lower than men. Elderly men and women showed a similar pattern, with 1.14m/s for elderly men and 1.10m/s for elderly women, which showed statistical significance by T-test.

2-3. Impact of the Silver Zone

Not many studies have been conducted to evaluate the impact of the Silver Zone on elderly pedestrian traffic accidents so far.

New York City government_(2022) observed "Safe Street for Seniors" initiative of New York City and its safety treatments such as slowing vehicle speeds, reducing pedestrian exposure, slowing turns and providing pedestrian refugees (pedestrian islands) have significantly decreased elderly pedestrians traffic accidents.

Table 2 Example of Safe Street for Seniors Program (New York City, 2022)

Location (Year)	Treatment	Impact
Cropsey Avenue, Brooklyn (2018)	bus boarding islands, enhancements to paint and concrete median structures, the introduction of pedestrian refuge islands, and upgrades to markings	Total injuries decreased by 45%, pedestrian injuries by 67%
Sheepshead Bay Road, Brooklyn (2016)	Slip lanes closed off, concrete pedestrian refuges, one-way street conversions, pedestrian plaza spaces added, and adjustments to signal timing	Total injuries decreased by 18%, crashes with injuries decreased by 24%
Northern Boulevard, Queens (2014)	9 additional pedestrian refuge islands, left turn bays, moderated signal timing, crosswalks upgraded	Pedestrian injuries decreased by 30%, total injuries decreased by 12%
West End Avenue, Manhattan (2014)	Removed one travel lane in each direction, added left turn bays and wide parking lane stripes, installed 4 pedestrian refuge islands	Pedestrian injuries decreased by 45%, total injuries decreased by 29%

Most of the South Korean studies have focused on the Silver Zone facility inspection and evaluation whether they meet the facility installation standard set by the government regulations, and additionally analyzed traffic accident data but had mixed findings on the impact of the Silver Zone.

Ahn (2015) evaluated the Silver Zones installed in Busan City from 2008 to 2014 based on requirements listed in "The Rules on the Designation and Management of Areas for the Protection of Children, the Elderly, and Persons with Disabilities, Ministerial Decree of the Ministry of the Interior and Safety.

The researcher checked 1) proper zone signs from start point to end point with proper visibility 2) the width of crosswalks is at least 4.0m and raised crosswalks are installed 3) whether the sidewalk and roadway are separated and sidewalks are at least 2m 4) speed bump is installed 5) lighting facilities for nighttime pedestrians is installed 6) accessibility from the facility with the Silver Zone to the public transportation service 7) pedestrian traffic signal speed conforms with baseline speed(0.8m/s), which is slower than general standard speed(1.0m/s). 8) illegal parking detection cameras 9) traffic signals with pedestrian push buttons among 10 locations with the most frequent elderly traffic accidents from 2007 to 2014 in Busan city.

According to the investigation, the walking environment of the Silver Zone was not enough to guarantee the safety of elderly pedestrians.

Lee (2012) conducted a before-and-after study with a comparison group method to analyze the impact of the Silver Zone on elderly pedestrian traffic accidents by using traffic accident data within the Silver Zone from 2009 to 2011 in Gyong-Gi Province. The researcher found out that the Silver Zone was effective in reducing traffic accidents; 56% of reduction effect was observed when the Zone was designated within a 500m radius from a target facility, and 36% of reduction effect within a 300m radius from the target facility.

Choi & Yoon & Jung (2018) analyzed the Silver Zone data in Seoul city from 2007 to 2014 and elderly pedestrian traffic accident data from 2010 to 2015 with the DID method, and assessed whether the Silver Zones are located in proper locations.

They observed the Silver Zone was an ineffective measure in reducing traffic accidents as traffic collisions increased from the observed period without any statistical difference in both treatment and control areas. Also, they examined current locations did not coincide with higher traffic accident rates and pointed out the reason for a current the Silver Zone designation process – initiated by a request from the head of the target facility, not by deep studies on the accident patterns and planning process.

III. Research Design

3-1. Hypothesis

Based on the purpose of the study including research questions and literature review, this study will review the following hypothesis.

H1. Reduction in the death rate of elderly pedestrian traffic accidents is associated with the installation of the Silver Zone
H2. Reduction in the severe injury rate of elderly pedestrian traffic accidents is associated with the installation of the Silver Zone
H3. Reduction in the accident rate of elderly pedestrian traffic accidents is associated with the installation of the Silver Zone

H4. Silver Zone is more positively related to the reduced death rate of elderly females than their male counterparts.
H5. Silver Zone is more positively related to the reduced severe injury rate of elderly females than their male counterparts.
H6. Silver Zone is more positively related to the reduced accident rate of elderly females than their male counterparts.

3-2. Research Data

3-2-1. Data Overview

For the analysis, Seoul metropolitan city was selected as a target region as Seoul city's death rate of the traffic accidents within the Silver Zone district (18.2%) is the closer approximation to the nationwide death rate record (17.5%) (Ryu, J.B., Lee, S.W., Shim, T.I. & Lee, S.I., 2022) which can deduce the outcome from the Seoul city to the entire nation. Additionally, the city government has provided a well-managed open-source database website(data.seoul.go.kr) for more than decades.

The analysis period is between 2007 to 2022, as the national government initiated the Silver Zone in 2007, and the accessible data available to the public was up by 2022 when data collection was performed from April to May 2023.

Cumulative numbers of the Silver Zone installed by Dong were used and for the index to represent the elderly's traffic safety condition, the elderly pedestrian traffic accidents reported to the Police Force and managed by Korea Road Traffic Authority were utilized.

Regarding traffic accidents data, three kinds of open-source data- 1) the number of reported cases of elderly pedestrian accidents by Dong 2) the number of severe injuries –

accidents causing injuries that require more than 3 weeks of medical treatment (Korea National Police Agency, 2024) by Dong 3) the number of deaths released by Koroads in 2022 on its official website(https://taas.koroad.or.kr) were used.

3-2-2. Traffic Accident Data

This study uses traffic accident data reported to the Korea National Police Agency from the Korea Road Traffic Authority (Koroads) open-source data online platform TAAS (Traffic Accident Analysis System).

Based on Korea's Traffic Safety Act Article No. 52, and its presidential decree Article No. 48-2, the Koroads has been entrusted with managing traffic safety data collected from the National Police Agency, insurance companies, and credit unions.

Among the traffic accident data, I used 29,898 elderly pedestrian traffic accident data collected by the Police Agency from 2007 to 2022 in the Seoul area, which was structured by case identification numbers. They are composed of the legal district Dong where the accident occurred, the gender and age of the victim and perpetrator, the severity of the injury, and number of fatalities by accident.

Also, to identify a more accurate impact of the Silver Zone, three types of traffic accident data are lagged by one year behind the cumulative number of the Silver Zones. This approach allows for a better understanding of the relationship between the implementation of the Silver Zones and traffic accident trends.

3-2-3. The Silver Zone and Traffic Safety Facility Data

In this study, I used three types of traffic safety facility data including the Silver Zone, School Zone, and crosswalks installed from 2007 to 2022 in Seoul city which were collected and managed by the Seoul Metropolitan City government's data platform named "Seoul Open Data Plaza"(https://data.seoul.go.kr).

3-2-4. Others

Other than traffic accidents and traffic safety facility data, demographic data including overall population, the elderly population, population density, elderly population density structured by administrative Dong district were used.

Additionally, registered vehicle numbers and numbers of the elderly living alone and receiving basic income from the government were used for analysis.

3-2-5. Panel Data Creation and Analysis

For the analysis, I created a panel data type dataset using district Dong as a unit of analysis, with multiple kinds of open-source data from different government bureaus.

Panel data has characteristics of both cross-sectional data and time series data simultaneously by involving data investigated throughout multiple time points (Min et al., 2022). Ma and Kim (2007) pointed out the rising importance of panel data in urban transportation studies, in that it can clarify causal relationships of events through time-series investigations of microscopic units.

In this study, I intended to use Dong district- the smallest administrative district unit of South Korea- as an individual entity for the analysis, but each data was structured by a different type of Dong – one is administrative Dong, and the other is legal Dong, and only 12% of them are identically matched.

For this reason, I opted for a combination of legal Dong and administrative Dong as an individual entity and named it PID throughout the study.

Additionally, I created a dummy variable Gender, 1 is for the women and 0 for the men in the district Dong to identify how the Silver Zone's impact on reducing elderly pedestrian traffic accidents would be differentiated by gender.

In this manner, I produced 16,633 observations across 735 PIDs, spanning a period of 16 years from 2007 to 2022, including gender types (Male, Female).

Table 3 Description of the District Levels Used In the Study

District Level	No. of Values used in the study/ currently existing figures	Examples
Gu	25/25	Yong-San Gu
Legal Dong	457/467	Wonhyoro 1-ga, Wonhyoro 1-ga, Munbae-dong, Singye-dong
Administrative Dong	425/426	Won-hyo-ro 1-dong
PID(Unit of analysis)	735	Yong-San Gu + Wonhyoro 1-ga + Singye-dong

The observations' characteristics are explained in Table 4. Among all the 16,633 observations, 7,947 were male elderly pedestrians (47.78%) who fell victim to car accidents and 8,686 were female victims (52.22%) of elderly pedestrian accidents.

The mean registered population within the district Dong is 11,610, varying from 1 to 30,758 with a standard deviation of 4840.05. As for the elderly population registered within the district, the mean is 1560.47 and the standard deviation is 711.22.

Table 4 Descriptive Statistics of the Data in the Analysis

N= 16,633	Section	Frequency	%	
Gender	Male	7,947	47.78	
	Female	8,686	52.22	
Year	2007 ~ 2022			
Population	Year 2007 ~2022		(Mean)	(S.D)

		11,610	4840.05
Elderly population	Year 2011 to 2022	(Mean)	(S.D)
		1560.47	711.22

3-3. Measures

3-3-1. Dependent Variables

To evaluate the impact of the Silver Zone on elderly pedestrian traffic safety, this study uses three dependent variables regarding elderly pedestrian accidents: Death rate of elderly pedestrian accidents (death rate), Severe Injury rate of elderly pedestrian accidents (severe injury rate), traffic accident case rate of the elderly pedestrian accidents (accident rate) in Seoul from 2007 to 2022 by legal Dong.

To create rate data, I created the three rate variables by having the number of elderly pedestrian fatalities due to car accidents, the number of pedestrians with severe injuries, and the number of elderly pedestrian traffic accident cases by the registered elderly population in the district and multiplied the result by 10,000 to represent the rates per 10,000 elderly population.

In addition, to evaluate the impact of the Silver Zone installation on traffic accidents more accurately, I used one-year lagged variables for the traffic accident data.

Table 5 explains descriptive statistics of dependent variables. As rate values including death rate, severe injury rate, and accident rate used elderly population which exists from 2011 to 2022, observations are less than 11,514 out of 16,633.

Also, the mean values of death rate, severe injury rate, and accident rate between genders show differences, with the rate for females being higher than that for males. The statistical significance of the gender difference will be further elaborated in chapter IV. Data Analysis and Results section.

Table 5 Descriptive Statistics of Dependent Variables

Variable	Obs	Mean	S.D	Min	Max
Death rate	11,514	2.12	6.43	0	338.98
Death rate (Female)	6,316	2.20	6.64	0	338.98
Death rate(Male)	5,198	2.01	6.17	0	232.56
Gender Gap (Female-Male)		**0.19**	**0.12**		
Severe injury rate	10,733	28.77	42.93	0	1489.36
Severe injure rate (Female)	5,579	34.28	44.73	0	1290.3
Severe injury rate (Male)	5,154	22.82	40.05	0	1489.36
Gender Gap (Female-Male)		**11.46**	**0.82**		
Accident rate	11,514	47.88	69.02	2.39	1935.48
Accident rate (Female)	6,316	55.19	72.99	2.39	1935.48
Accident rate (Male)	5,198	42.64	63.47	2.87	1914.89
Gender Gap (Female-Male)		**9.54**	**1.29**		

3-3-2. Independent Variables

To examine the impact of the Silver Zone on the traffic safety of the elderly, the number of the Silver Zones installed cumulated in total within the district was used. The

Silver Zone of Table 5 describes descriptive statistics of independent variables that were used.

As displayed in Table 6, the mean of the accumulated amount of the Silver Zone is 0.50, which ranges from 0 to 6 and the standard deviation of it is 1.00.

Table 6 Descriptive Statistics of the Independent Variable (Silver Zone cumulated)

Variable	Obs	Mean	S.D	Min	Max
Silver Zone(cumulated)	16,633	0.50	1.00	0	6

When it comes to the distribution of zones, districts without any single zones (number of installed silver zone: 0) are the most prominent, as explained in Table 6. 69.39% of observations had 0 Silver Zone from 2007 to 2022, and 23.71% have 1 Silver Zone. The proportion of districts with more than 2 Silver Zones is only 8.77%.

Table 7 Distribution of the Silver Zone Within Dong District

N=16,633	Section	Frequency	%
Silver Zone(cumulated)	0	11,542	69.39
	1	3,716	22.34
	2	515	3.10
	3	332	2.00
	4	232	1.39
	5	208	1.25
	6	88	0.53

3-3-3. Control Variables

To minimize the external factors that might have affected the impact of Silver Zone on elderly pedestrian safety and improve the precision of the analysis, 6 variables were controlled: population, School Zone, Crosswalks, registered vehicles, population density, and lower-income elderly population.

Residents

The registered number of residents within Dong district managed by Seoul city government from 2007 to 2022 was used.

School Zone

A cumulative number of school zones that were installed within the district was used. Since School Zone was initiated in 1995, the accumulated number of zones that were built before 2007 are also included within the dataset.

Crosswalks

A cumulative number of crosswalks was also monitored. Crosswalks include both those with traffic signals and those without signals. Values regarding crosswalks that were installed before 2007 were also accumulated on the dataset.

Registered vehicles

Registered vehicles within the district were used, but the data started to be managed by Dong level, so observations exist from 2015 to 2021 and have missing values from 2007 to 2014.

Population density

For Population density, the number of residents per square kilometer within the district was used as the control variable.

Elderly income status

To include the income status of the elderly, I used the elderly population receiving basic income from the government and living alone. The mean of it is 236.52 and the standard deviation is 156.39. This data is managed by Dong level since 2015, so the observations are observed from 2015 to 2022, and have missing values from 2007 to 2014.

Table 8 Descriptive Statistics of Control Variables

N = 16,633	Obs	Mean	Std. dev.	Min	Max
Residents	16,208	11610.99	4840.054	1	30758
School Zone	16,633	8.85	12.05	0	63
crosswalks	16,633	490.3477	435.9734	0	2,097
Registered vehicles	7,350	7328.211	3634.455	565	30,101
Population density	11,266	11275.34	6353.69	36.96	56742.31
Elderly receiving basic income and living alone	7,929	236.52	156.39	1	466

3-3-4. Research Model & Methodology

This study aims to evaluate the impact of the Silver Zone on the traffic safety of elderly pedestrians, focusing on elderly pedestrian traffic accidents that occurred within the unit of analysis by panel data analysis.

Data cleaning and quantitative research methods were conducted using STATA17 with a significance level of 5% (0.05).

To clarify the research question and hypothesis, a panel data regression model has been applied. In detail, either a random effect or fixed effect regression model can be a possible candidate for the analysis, and the Hausman test - the method of comparing RE (Random Effects) estimates and FE (Fixed Effects) estimates - has been widely used to determine the methodology. (Han, 2021). The null hypothesis of the Hausman test is that there is no statistical difference in estimates of random effects and fixed effects by measuring the difference between estimators of random effects and fixed effects. If the null hypothesis is rejected, the fixed effect model will be chosen. On the other hand, if the null hypothesis is accepted, the random effect model will be the alternative.

H_0: cov(x_{it},u_i) = 0 / Random effect Model is chosen.
H_1: cov(x_{it},u_i) ≠0 / Fixed effect Model is chosen.

As the study has three different dependent variables – death rate, severe injury rate- and two gender types (female and male), a total of six kinds of Hausman tests were conducted. The test results indicate that, following the below process on Table 20, the fixed effects are found to be more appropriate.

All six results rejected null hypothesis and supported fixed effect model. For example, the test result of elderly female's death rate on table 20, P value is less than 0.01, which suggests the null hypothesis is rejected and the fixed effect model is found to be a more appropriate method for the data analysis.

Table 9 Hausman Test Result For Female Elderly 's Death rate

Gener = female Dependent var: death rate	Coefficient		(b-B)	$\sqrt{diag(Vb - VB)}$
	(b)	(B)		
Variable	**Fe**	**Re**	**Difference**	**S.E**
Silver Zone	-.3203637	.0644813	-.384845	.2535161
Crosswalk	-.0115543	.0028271	-.0143814	.0036447
School Zone	.0340737	.0036213	.0304524	.0512305
Residents	-.0000397	-.0001673	.0001276	.00025
Vehicles	-.0003454	-.0000822	-.0002632	.0002627
Population density	-.0003052	-.0000411	-.000264	.0001733
Income status	-.0002957	-.0008302	.0005346	.0004475

Note

'b' denotes coefficients consistent under both null (H0) and alternative (Ha) hypotheses, obtained from panel data fixed effect regression model. 'B' denotes coefficients inconsistent under the alternative hypothesis (Ha) but efficient under the null hypothesis (H0), obtained from panel data random effect regression model. The Hausman test statistic is calculated as chi2(7) = (b - B)'\[(V_b - V_B)^(-1)\](b - B) = 36.30, with a p-value < 0.0001, indicating a significant difference in coefficients between fixed effects and random effects models. The significant p-value suggests that the difference in coefficients is systematic, indicating that the random effects model may not be appropriate for the data.

The table below displays that all variables consistently fit to fixed effect model to make data analysis by comparing the chi-square significance of six kinds of variables. Detailed Hausman test result is included in the 6.1. Appendix part.

Table 10 Fitted model for each dependent variable

Dependent variables	Sig	Fitted Model
Death rate/Male	0.000***	Fixed Effects
Death rate/Female	0.000***	Fixed Effects
Severe injury rate/Male	0.000***	Fixed Effects
Severe injury rate/Female	0.000***	Fixed Effects
Accident rate/Male	0.000***	Fixed Effects
Accident rate/Female	0.000***	Fixed Effects

*** $p < 0.01$

In this regard, the primary fixed effect model for the three dependent variables is deducted below in table 11.

Table 11 Model for Dependent Variables

Dependent variable	Model
Death rate	$Death_{it} = \beta_0 + \beta_1 \times Silver\ Zone_{it} + \beta_2 \times Residents_{it} + \beta_3 \times School\ Zone_{it} + \beta_4 \times crosswalks_{it} + \beta_5 \times Vehicles_{it} + \beta_6 \times density_{it} + \beta_7 \times income_{it} + \alpha_i + \varepsilon_{it}$
Severe injury rate	$Injury_t = \beta_0 + \beta_1 \times Silver\ Zone_{it} + \beta_2 \times Residents_{it} + \beta_3 \times School\ Zone_{it} + \beta_4 \times crosswalks_{it} + \beta_5 \times Vehicles_{it} + \beta_6 \times density_{it} + \beta_7 \times income_{it} + \alpha_i + \varepsilon_{it}$
Accident rate	$Accident_{it} = \beta_0 + \beta_1 \times (Silver\ Zone_{it} \times gender_{it}) + \beta_2 \times Residents_{it} + \beta_3 \times School\ Zone_{it} + \beta_4 \times crosswalks_{it} + \beta_5 \times Vehicles_{it} + \beta_6 \times density_{it} + \beta_7 \times income_{it} + \alpha_i + \varepsilon_{it}$

Furthermore, to identify the interaction effect of gender on the installation of the Silver Zone, the Gender variable is also accumulated on the model below in Table 18.

Table 12 Model per Dependent variable (Interaction effect of gender included)

Dependent variable	Model with interaction effect of gender included
Death rate	$Death_{it} = \beta_0 + \beta_1 \times (Silver\ Zone_{it} \times Gender_{it}) + \beta_2 \times Residents_{it} + \beta_3 \times School\ Zone_{it} + \beta_4 \times Crosswalks_{it} + \beta_5 \times Vehicles_{it} + \beta_6 \times Density_{it} + \beta_7 \times Income_{it} + \alpha_i + \varepsilon_{it}$
Severe injury rate	$Injury_{t} = \beta_0 + \beta_1 \times (Silver\ Zone_{it} \times Gender_{it}) + \beta_2 \times Residents_{it} + \beta_3 \times School\ Zone_{it} + \beta_4 \times Crosswalks_{it} + \beta_5 \times Vehicles_{it} + \beta_6 \times Density_{it} + \beta_7 \times Income_{it} + \alpha_i + \varepsilon_{it}$
Accident rate	$Accident_{it} = \beta_0 + \beta_1 \times (Silver\ Zone_{it} \times Gender_{it}) + \beta_2 \times Residents_{it} + \beta_3 \times School\ Zone_{it} + \beta_4 \times crosswalks_{it} + \beta_5 \times Vehicles_{it} + \beta_6 \times Density_{it} + \beta_7 \times Income_{it} + \alpha_i + \varepsilon_{it}$

IV. Data Analysis and Results

4-1. Fixed effect regression result

Fixed effect regression has been performed on three distinct dependent variables categorized by gender. The coefficient for all three dependent variables by gender consistently exhibits negative values. This implies that the installation of the Silver Zone is associated with a decrease in death rate, severe injury rate, and accident occurrence rate for both females and males.

While the result is also statistically significant with P value less than 0.01 in severe injury rate and accident rate for both male and female, it is not statistically significant for the death rate of both males and females (0.300 for female, 0.953 for male) as summarized on table 19. At the same time, other external conditions such as population, number of vehicles, number of school zones, and crosswalks are controlled.

Table 13 Fixed Effect Regression Result

Independent variable: Silver Zone	Dependent variable	Coefficient	Std. err.	t	P>|t|	95% conf. interval	
female	Death rate	-0.320	0.309	-1.040	0.300	-0.926	0.286
	Severe Injury rate	-7.075	1.219	-5.810	0.000***	-9.465	-4.686
	Accident Rate	-10.844	1.764	-6.150	0.000***	-14.303	-7.386
Male	Death rate	-0.015	0.258	-0.060	0.9530	-0.521	0.491
	Severe Injury rate	-3.915	1.325	-2.950	0.003**	-6.513	-1.316
	Accident Rate	-8.102	1.797	-4.510	0.000***	-11.624	-4.579

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4-2. Interaction effect of gender (female)

The second part of the analysis of the study is the interaction effect between dependent variables and the gender, females. As the death rate did not show statistical significance, this dependent variable was excluded from the analysis, and severe injury rate and accident rate were used.

For the variable severe injury rate, the original coefficient is – 0.419, but it changes into 1.192 with statistical significance (p-value <0.001) when the interaction effect is included. The accident rate variable also shows a similar pattern as the coefficient of it is -6.475 but the coefficient changes to 5.780 when the interaction effect is involved.

The results imply that the effect of the Silver Zone on the dependent variables is different for the different genders, and it is more likely to be effective for the male elderly compared to the female elderly.

This result is contrary to the hypothesis (H4, H5, and H6) that the Silver Zone might be more effective in reducing female elderly pedestrian traffic accidents compared to the male elderly. Considering the female elderly are the primary victims of pedestrian traffic accidents by vehicles, this raises questions about whether the Silver Zone is functioning properly to reduce traffic accident and enhance traffic safety and additional study should be conducted further to examine the reason and provide suggestions.

Table 14 Interaction Effect of Gender

Independent var: Silver Zone	Coefficient	Std. err.	z	P>z	[95% conf. interval]	
Severe injury rate	-.419	.0511	-8.19	0.000***	-.519	-.319
Severe injury rate- Interaction effect of gender	1.192	.0469	25.43	0.000***	1.100	1.284
Accident Rate	-6.475	0.761	-8.510	0.000***	-7.966	-4.984
Accident Rate- Interaction effect of gender	5.780	0.580	9.960	0.000***	4.642	6.917

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

V. Findings and Conclusion

5-1. Findings

So far, the impact of the Silver Zone on reducing traffic accidents among the elderly has been debatable and the former studies showed inconsistent results.

In this study, the result of regression analysis shows that the Silver Zone is a meaningful policy tool in a way that it is found to be efficient in reducing severe injury rate and accident rates of the elderly pedestrians, but it is not statistically significant for the death rate.

On the other hand, it is not necessarily more associated with reducing traffic accidents among the female elderly, who are the most prominently vulnerable population to the traffic accident above all, which fades the outcome of the policy.

This might be followed by those inferences below but should be studied further to be clarified.

- The Silver Zone is more likely to be effective in preventing accidents among reckless pedestrians, who are more likely to be male.
- In selecting locations for the Silver Zone, lacking consideration for elderly women who are more vulnerable to traffic accidents.

5-2. Limitations and Suggestions for the Further Study

The finding of the study has limitations and further study should be conducted together with solving these issues below.

First, the possibility of reverse causality cannot be excluded, as the Silver Zone is often installed in locations with severe traffic accidents with casualties after the accidents. In other words, the Silver Zone contributed to a reduction in traffic accidents, but prior accident rates could have led to the installment of the Silver Zone.

Second, the result cannot dismiss the possibility that other factors, such as development in traffic conditions & infrastructure like unmanned cameras, may influence the accident patterns.

Third, the data includes all the elderly pedestrian traffic accidents within the unit of analysis (district Dong), but more detailed data such as traffic accidents within the actual Silver Zone should be analyzed.

Lastly, more detailed conditions that may affect the occurrence of traffic accidents such as weather, time, and roadway condition should be included for more accurate analysis.

5-3. Conclusions

In this study, I analyzed the impact of the Silver Zone from two perspectives: First, changes in three forms of elderly pedestrian traffic accidents one year after the cumulative number of the Silver Zone was counted were assessed. Second, the interaction effect of gender in the three forms of traffic accidents was assessed to see whether the more vulnerable group – the female elderly- is benefitted from the Silver Zone installations.

As discussed above, the installation of the Silver Zone is associated with a reduction in severe injury rate and traffic accident rate, but it did not display statistically significant results for the death rate. Also, the Silver Zone is not more likely to be effective in reducing the traffic accidents of female elderly pedestrians compared to the male elderly.

Regardless of the results and limitations, this study has strengths in that it applied more detailed data analysis with a wider range of timeframe and finer unit of analysis using fixed effect regression analysis.

Furthermore, future research should delve deeper into the intersectionality of age and gender within the realm of elderly traffic safety. Such exploration is crucial as findings are likely to vary significantly across different age groups and genders, offering valuable insights for the development of traffic safety policies tailored to the specific needs of the elderly population.

VI. Appendix

Hausman result

Death rate for female

	coefficient			
	(b)	(B)	(b-B)	$\sqrt{\text{diag}(Vb - VB)}$
	Fixed effect	Random effect	Difference	Standard Error
Total zone	-.3203637	.0644813	-.384845	.2535161
cross	-.0115543	.0028271	-.0143814	.0036447
school	.0340737	.0036213	.0304524	.0512305
pop	-.0000397	-.0001673	.0001276	.00025
auto	-.0003454	-.0000822	-.0002632	.0002627
density	-.0003052	-.0000411	-.000264	.0001733
baseinc_old	-.0002957	-.0008302	.0005346	.0004475

b = Consistent under H0 and Ha; obtained from panel data regression

B = Inconsistent under Ha, efficient under H0; obtained from panel data regression

Test of H0: Difference in coefficients not systematic

chi2(7) = $(b-B)'[(V_b-V_B)^{-1}]$ (b-B) = 36.30 Prob > chi2 = 0.0000

Severe injury rate for female

	coefficient			
	(b)	(B)	(b-B)	$\sqrt{\text{diag}(Vb - VB)}$
	Fixed effect	Random effect	Difference	Std. err.
totalzone	-7.075498	-2.469865	-4.605633	.8399405
cross	-.1413106	.0522178	-.1935284	.0143034
school	.0335694	.2274923	-.1939228	.1923402
pop	-.0061199	-.0012946	-.0048253	.0009534
auto	-.0030314	-.0025033	-.0005282	.0009876
density	-.0009174	.000067	-.0009844	.0006675
baseinc_old	.0008238	-.0001711	.000995	.000467

b = Consistent under H0 and Ha; obtained from panel data regression

B = Inconsistent under Ha, efficient under H0; obtained from panel data regression

Test of H0: Difference in coefficients not systematic

chi2(7) = $(b-B)'[(V_b-V_B)^{-1}]$ (b-B) = 472.35 Prob > chi2 = 0.0000

Accident rate for female

	(b)	(B)	(b-B)	$\sqrt{\text{diag}(Vb - VB)}$
	Fixed effect	Random effect	Difference	Std. err.
totalzone	-10.84439	-3.89182	-6.952569	1.184012
cross	-.1767571	.0866326	-.2633897	.0205767
school	.0444145	.3562859	-.3118714	.2762858
pop	-.007891	-.0021669	-.005724	.0013726
auto	-.0045228	-.0036989	-.0008239	.0014161
density	-.0017909	.0001379	-.0019288	.0009626
baseinc_old	.0003997	-.0006579	.0010575	.0005941

b = Consistent under H0 and Ha; obtained from panel data regression

B = Inconsistent under Ha, efficient under H0; obtained from panel data regression

Test of H0: Difference in coefficients not systematic

chi2(7) = $(b-B)'[(V_b-V_B)^{-1}]$ (b-B) = 498.07 Prob > chi2 = 0.0000

Death rate for male

	(b)	(B)	(b-B)	$\sqrt{\text{diag}(Vb - VB)}$
	Fixed effect	Random effect	Difference	Standard Error
Total zone	-.0151255	-.0324445	.017319	.1974961
cross	-.0111141	.0024821	-.0135962	.0030637
school	-.0038072	-.0196951	.0158879	.033654
pop	-.0006181	-.0001026	-.0005156	.0002229
auto	-.000414	-.0001636	-.0002505	.0002146
density	.0000383	-.0000678	.0001061	.0001519
baseinc_old	-.0004632	-.0002108	-.0002524	.0003058

b = Consistent under H0 and Ha; obtained from panel data regression

B = Inconsistent under Ha, efficient under H0; obtained from panel data regression

Test of H0: Difference in coefficients not systematic

chi2(7) = $(b-B)'[(V_b-V_B)^{-1}]$ (b-B) = 42.21 Prob > chi2 = 0.0000

Severe injury rate for male

	(b)	(B)	(b-B)	$\sqrt{\text{diag}(Vb - VB)}$
	Fixed effect	Random effect	Difference	Standard Error
totalzone	-3.914555	-1.177476	-2.737078	1.00451
cross	-.1386382	.0333825	-.1720206	.0157537
school	.0691567	.0452293	.0239273	.1831169
pop	-.0116529	-.0016376	-.0100154	.0011465
auto	-.004281	-.0014039	-.0028771	.0011043
density	.0014927	-.0001675	.0016602	.0007815
baseinc_old	-.004173	-.0056499	.001477	.

b = Consistent under H0 and Ha; obtained from panel data regression

B = Inconsistent under Ha, efficient under H0; obtained from panel data regression

Test of H0: Difference in coefficients not systematic

chi2(7) = $(b-B)'[(V_b-V_B)^{-1}]$ (b-B) = 366.2 Prob > chi2 = 0.0000

Accident rate for malea

	(b)	(B)	(b-B)	$\sqrt{\text{diag}(Vb - VB)}$
	fe3	re3	Difference	Standard Error
totalzone	-8.101581	-2.833562	-5.268019	1.282498
cross	-.173765	.0631317	-.2368967	.0212831
school	.014038	.0955837	-.0815457	.2289413
pop	-.0177329	-.0030903	-.0146426	.001536
auto	-.0059182	-.0025043	-.0034139	.0014699
density	.0017553	-.0003693	.0021246	.0010507
baseinc_old	-.0027422	-.0054134	.0026711	.

b = Consistent under H0 and Ha; obtained from panel data regression

B = Inconsistent under Ha, efficient under H0; obtained from panel data regression

Test of H0: Difference in coefficients not systematic

chi2(7) = $(b-B)'[(V_b-V_B)^{-1}]$ (b-B)

= 417.48

Prob > chi2 = 0.0000

VII. References

Chen, L., Chen, C., Ewing, R., McKnight, C. E., Srinivasan, R., & Roe, M. (2013). Safety countermeasures and crash reduction in New York City—Experience and lessons learned. Accident Analysis and Prevention, 50, 312-322. 10.1016/j.aap.2012.05.009.

Choi, Y., Yoon, H., & Jung, E. (2018). Do Silver Zones reduce auto-related elderly pedestrian collisions? Based on a case in Seoul, South Korea. Accident Analysis & Prevention, 119, 104-113.

Coffin & Morrall (1995). Walking Speeds of Elderly Pedestrians at Crosswalks, Transportation Research Record 1487, 63-67.

Ghani, F., Rachele, J. N., Washington, S., & Turrell, G. (2016). Gender and age differences in walking for transport and recreation: Are the relationships the same in all neighborhoods? Preventive Medicine Reports, 4, 75-80. 10.1016/j.pmedr.2016.05.001

Han, C. (2021). Panel Data Lecture (3rd ed.). Parkyoungsa. p. 132.

Ma, Kang-Rae, & Kim, Chan-Sung (2007). Recent Research Trends and Issues in Urban Transportation Panel Data Analysis, Transport Policy Research Volume 14 Issue 2 December 2007. P.5.

Korea National Police Agency (2024). Road Traffic Act Enforcement Regulations Appendix 28.

KTV. (2007). Program: Aging Society Project: Companion. Retrieved March 7, 2024, from https://m.ktv.go.kr/program/again/view?program_id=PG1110912D&content_id=67329

Li, P., Kang, P., Burns, S., Bahetibieke, A., & Report, F.NYU CUSP Urban Science Intensive II Senior Pedestrians in NYC: A Diff-in-Diff Approach to Evaluating Safe Streets for Seniors.

Lobjois, R., & Cavallo, V. (2007). Age-related differences in street-crossing decisions: The effects of vehicle speed and time constraints on gap selection in an estimation task. Accident Analysis and Prevention, 39(5), 934-943. 10.1016/j.aap.2006.12.013.

Lam, O. (2019, December 3). Using fixed and random effects models for panel data in Python. Pew Research Center: Decoded(https://www.pewresearch.org/decoded/2019/12/03/using-fixed-and-random-effects-models-for-panel-data-in-python/).

OECD (2024), Fertility rates (indicator). doi: 10.1787/8272fb01-en (Accessed on 03 March 2024).

Ryu, J.B., Lee, S.W., Shim, T.I. & Lee, S.I. (2022). Silver Zone Traffic Safety Facility operation strategy research, Korea Road Traffic Authority Traffic Science Institute.

Seoul Metropolitan Government. (2024). Seoul's district 'Dong' per district 'Gu'. Retrieved January 24, 2024, from https://www.seoul.go.kr/seoul/autonomy_sub.do.

Visby, R. H., & Lundholt, K. (2018). Gender Differences in Danish Road Accidents. Transportation Research Record, 2672(3), 166-174. 10.1177/0361198118795005

Yuna Noh, Minjae Kim & Yoonjin Yoon (2018) Elderly pedestrian safety in a rapidly aging society—Commonality and diversity between the younger-old and older-old, Traffic Injury Prevention, 19:8, 874-879, DOI: 10.1080/15389588.2018.1509209.

Wilmut, K., & Purcell, C. (2022). Why Are Older Adults More at Risk as Pedestrians? A Systematic Review. Human Factors, 64(8), 1269-1291. 10.1177/0018720821989511

Open data portal (2023), Traffic accidents statistics by victims’ age and gender(Korea Road Traffic Authority), Retrieved March 4, 2024, from https://www.data.go.kr/data/15070293/fileData.do.