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Do Silver Zones reduce auto-related elderly pedestrian collisions? Based on a case in Seoul, South Korea

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ABSTRACT

Inaugurated in 2007, in Seoul, South Korea, the Silver Zone is a designated pedestrian safety zone for the elderly that adopts speed limit measures such as traffic signage and road surface markings. In this study, we empirically investigate the effectiveness of the Silver Zone in two respects: first, whether the establishment of the Silver Zone has lowered the number of elderly pedestrian collisions, and second, whether Silver Zones are established in the appropriate areas, that is, those with the highest frequency of such collisions. From our quasi-experimental statistical analysis, Difference-in-Difference, we learn that the Silver Zone has no effects on reducing elderly pedestrian collisions. From our spatial statistical analyses—Kernel Density mapping and Bivariate Moran's I—we found a spatial mismatch between the frequency of senior pedestrian-vehicular collisions and the location of Silver Zones. For better performance of the Silver Zone system, we suggest additional types of physical measures to be integrated into the Silver Zone system. Municipal-level comprehensive master plan for Silver Zone system is also necessary, under which local governments should use periodic surveys to inventory and prioritise the locations of highest elderly pedestrian-vehicular collisions.

1. Introduction

As the world's population rapidly ages, with the ratio of the elderly[1] growing from the current 11% to 22% of the population by 2050 (United Nations, 2015), many societies have made efforts to create healthier and safer environments for senior citizens (Zhao, 2014; Li and Zhao, 2015). Improving neighbourhood walkability, as an integral part of daily life, is one strategy towards this goal (Hahm et al., 2017; Kim et al., 2014). Walking is both a means of exercise and transportation for the elderly. As they experience physical and cognitive losses, they forgo driving and taking public transit to avoid collisions, while maintaining physical activity (Piatkowski et al., 2015; Burbidge and Goulias, 2009).

Elderly pedestrian-vehicular collisions, however, are a serious problem (Rosenbloom et al., 2016; Cœugnet et al., 2017). While pedestrian deaths account for 22% of all vehicle-related casualties, approximately 40% of those involve the elderly[2] (International Transport Forum, 2014). This number has been increasing along with the aging population in many member countries of the Organization for Economic Co-operation and Development (OECD). Especially, increase of the traffic volume in high-density cities in the East Asia is a threat to elderly pedestrian safety (Zhao et al., 2014). South Korea is no exception. Currently, elderly pedestrian collisions account for 40% of all vehicle-related casualties (International Transport Forum, 2014; Whi, 2015).

In order to protect elderly pedestrians from collisions, the South Korean government established the Silver Zone system in 2007. The system mandates areas as safety zones where speed-limit measures, such as traffic signage and road surface markings, caution drivers about the presence of elderly pedestrians. The similar systems in other countries are Silver Zone[3] and Green Man Plus system[4] in Singapore and Safe Routes for Seniors program[5] in the U.S.A. (Fwa, 2016; Tan,

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[1] Age group of 60+
[2] Age group of 65+
[3] Singapore's National project to enhance road safety for seniors, since 2014.
[4] Technology to help the elderly cross the road more comfortably without adversely affecting the traffic flow by giving more green light time.
[5] City-wide project to improve pedestrian infrastructure for seniors in the U.S.A.

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2008; Transportation Alternatives, 2009).

Since the inception and spreading implementation of the Silver Zone, however, questions have been raised about its effectiveness in reducing collisions. Although some analytical research has pointed to the ineffectiveness of these approaches (Park and Oh, 2011; Lee, 2012), and the media has speculated about possible reasons for its failures, the lack of relevant data has prevented a full assessment of its performance. The accumulated number of Silver Zones in Seoul reached 80 in early 2016, but it was not until 2010 that the database on the pedestrian collisions became available by the Korea Road Traffic Authority.

In this study, we empirically investigate the effectiveness of the Silver Zone in two respects: first, whether the establishment of Silver Zones has lowered the number of elderly pedestrian-vehicular collisions, and second, whether Silver Zones were established in the appropriate areas, that is, those with the highest frequency of such collisions. To better evaluate Silver Zone program, we not only focused on the effect of Silver Zone, but also the effect of ten other physical elements in the zone, which may have effects on the frequency of collisions. With the analytical results, we further explore ways to improve the performance of Silver Zones.

For the first question, we use generalised linear modelling: Zero Inflated Poisson (ZIP), Zero Inflated Negative Binomial (ZINB), Zero Truncated Poisson (ZTP) and Zero Truncated Negative Binomial (ZTNB) in Difference-in-Difference, one of the quasi-experimental specifications. To answer the second question, we use spatial statistical analyses, namely, the Kernel Density estimation and Bivariate Local Moran's I.

The present study is the first attempt to investigate the environmental components of the Silver Zones that explain the elderly pedestrian-vehicular collisions, and the spatial alignment of the zones and the collision locations. Our multi-pronged evaluation will provide a more comprehensive understanding of the performance of Silver Zones, and thereby be a useful reference for municipalities wanting to improve the current system.

The structure of this study is as follows. In the next section, we briefly review the literature on Silver Zones in South Korea, followed by a description of our analytical methods. After presenting our analytical design, we describe the results, including an overview of the actual effects of Silver Zones as well as the other environmental factors on pedestrian collisions, and the degree of spatial alignment between the designated Silver Zones and senior pedestrian-vehicular collision spots. The final section discusses the implications of our findings and future research direction.

2. Background

2.1. Pedestrian safety

Safety zones are purposed to protect pedestrians from vehicles, adopting a number of safety measures and techniques. School Zone and Silver Zone are some of those examples, made for protecting children and the elderly, respectively, and are established in areas where a large volume of such populations gather. School Zones are commonly located around schools and day-care facilities to help children's commuting safer. Silver Zone is relatively newer than the School Zone system, conceived in response to the increasing concern on the aging society. Japan is a pioneer of Silver Zone since 1986, and South Korea and Singapore have adopted the system recently (Ibrahim, 2003; Fwa, 2016; KoRoad, 2012).

Safety Zones adopt traffic calming measures and techniques, to limit the speed of vehicles. In most of the safety zones, cars are not allowed to drive faster than 20mph (30 km/h). To inform drivers about the condition, speed signs are installed in the entrance and the exit of the zone. Within the zones, speed humps, smaller corner radii, pavement treatment, and chicane are deployed to physically and visually deter drivers from speeding. Also, more frequent and brighter lighting and fences are installed to help pedestrians walk with caution. Occasionally, surveillance cameras are operated to warn the drivers and detect the violation (Lee et al., 2013).

2.2. Silver Zone

In South Korea, to address the increasing elderly pedestrian-vehicular collisions, the Ministry of Government Administration and Home Affairs (MOGAHA) established the legal framework for the Silver Zone system, with the passage of the Road Traffic Act in May 2007. Since then, as of September 2016, a total of 746 zones have been created in South Korea, of which 80 are located in Seoul (Ministry of Government Administration and Home Affairs, 2016; Kim, 2015).

The Silver Zone designation is initiated by the requests from the heads of public or private facilities for seniors, such as senior welfare centres, medical institutions, sports centres and parks. Where the request is granted, a safety zone is created with special treatment to vehicular roads within a 300- to 500-metre radius outward from the facility (Ministry of Public Administration and Security, 2012). The borough, the city government and the police department coordinate efforts to manage the Silver Zones thereafter.

In the Silver Zones, the speed is limited to below 30 km/h, and the zone-designation and speed-limit signage is installed. Road surface is marked with colouring in red-brown and lettering the phrase "Silver Zone". Occasionally, extra measures are added, such as fences, speed bumps, elevated crosswalks, reduced crosswalk slope, realignment to one-way traffic, widened pedestrian pathways, and speed and signal cameras (Ministry of Public Administration and Security, 2012).

However, previous studies, using Before-After evaluation methods, suggested that Silver Zones have no or only a slight effect in reducing collisions (Lee, 2012; Park and Oh, 2011). Lee (2012) analysed the effects of Silver Zone by types of senior care facility, shapes of Silver Zone boundary (rectangular, T, Y, L, and I shape), and the locations of Silver Zone (at the corner or along the straight road). In Lee (2012), Silver Zone was partially effective in reducing collisions at some locations. Park et al. (2010) found that Silver Zone is effective in reducing the severity of collision by 9.5% but showed only a slight effect, 1.6%, in reducing the number of collision. Anecdotal evidence points to the impracticality of the speed reduction measures the system currently adopts, and pressing the necessity of more vigorous enforcements such as speed and signal cameras, speed bumps and radar speed signs (Kim, 2017). Some editorials also argue that the lack of consideration on the previous collision records leads to failure in prioritizing Silver Zones in the collision-prone spots (Choi, 2015; Yoon, 2013; Lim, 2015; Lee, 2015). Silver Zones are established only when the requests are made, thus locations with high collision rates could have been left untreated if such request was not made (Busan Ilbo, 2016; Park, 2016).

2.3. Analytical methodology

2.3.1. Poisson, negative binomial, ZIP, ZINB, ZTP and ZTNB in difference-in-difference approach

The Difference-in-Difference (DID) approach is one of the quasi-experimental analyses frequently used to evaluate the impact of policy interventions, since it is useful for inferring near-causality in observational studies (Li et al., 2012; Chabé-Ferret, 2015; Dempsey and Plantinga, 2013; Wang and Shi, 2012; Pope and Pope, 2012). DID estimates the effects of interests by comparing the outcome from the treatment and control groups in two different time periods: usually before and after the treatment. While the treatment group is exposed to the intervention only in the after period, the control group does not receive treatment during either period or receives treatment during both periods. By deducting the difference in the outcomes between the two groups with and without the treatment, in the periods before and after the treatment, we can understand the remaining "difference-in-difference" as a pure impact of the treatment, controlling for all other factors that simultaneously affect both groups, in the before and after periods (Pope and Pope, 2012).

Data of collisions have special characteristics: The number of collisions per street segment during a certain time period is discrete and generally small or zero. Since collisions are rare events, the count of segments with zero collisions tends to be high. Poisson and Negative Binomial, and their zero-truncated and zero-inflated options are such distribution explaining collision data. The Poisson distribution illustrates the probability of observing discrete numbers of events in a given time (Bradshaw et al., 2009), and thus, has been adopted in many transportation studies (Pérez et al., 2007; Dong et al., 2014; Lord et al., 2005): The distribution, however, assumes the mean and variance to be identical, and for that to be the case, the probability of an event occurrence is identical and independent throughout the entire time period (Chang et al., 2014; Hardin and Hilbe, 2012). The strict assumption of this single-parameter model is often inappropriate to apply to real-life data. The Negative Binomial distribution relaxes this assumption, and has been used for accommodating the condition of overdispersion (Wooldridge, 2016; Hardin and Hilbe, 2012).

In case of excessive or non-zero counts in data, zero-inflated and zero-truncated specifications of the Poisson or Negative Binomial modelling are adopted. These specifications identify the probability of the outcome value zero, then separate or exclude it, respectively, from the distribution of the rest of the outcome values. In zero-inflated approaches, the model is divided into two parts: first, the binary part to determine whether observations fall in a condition of taking only zero value, and second, the Poisson or Negative Binomial part to predict the rest of the counts. In zero-truncated models, the probability of the outcome value zero is taken out by adjustment on their original–Poisson or Negative Binomial–distribution (Nelson, 1977; Keeley et al., 1978; Hardin and Hilbe, 2012).

Transportation and crime research have used these models conventionally. Tipakornkiat (2014) used both the Poisson and negative binomial models to find the positive impact of safety rest areas for drivers in reducing the number of road accidents. Because of the overdispersion, the negative binomial model turned out to fit the data better. Schneider et al. (2010) also compared the Poisson and negative binomial models in assessing the association between the characteristics of roadway intersections and the risk of pedestrian collisions in Alameda County, California. For the same reason stated above, the negative binomial model outperformed the Poisson model. Ayati and Abbasi (2011) also selected the negative binomial over the Poisson model to find the impact of traffic volume in collisions on urban highways.

These two models are often compared with their zero-inflated versions. For example, Mouatassim and Ezzahid (2012) compared Poisson and zero-inflated Poisson (ZIP) to model the number of claims from Moroccan private health insurance. As a substantial portion of policyholders had not filed insurance claims during the study period, the ZIP regression performed better. Kim et al. (2015), using the ZINB model, suggested that drivers' demographic characteristics and the record of past traffic violations predict the number of collisions in South Korea. Since the data included a large portion of drivers who had never been involved with collisions, the zero-inflated model was a better choice for the dataset. The zero-truncated version of the Poisson and negative binomial models are used when the data do not contain any zero values. For example, Van Der Heijden et al. (2003) used ZTP to estimate the size of the criminal population. The crime report, the main dataset of the analysis, listed individuals who had been apprehended at least one time, thus the data did not include a zero value.

2.3.2. Spatial analysis: kernel density and bivariate local Moran's I

Kernel Density Estimation is a non-parametric statistical method used to visualise point patterns of data. By using moving windows focused on data points, so-called kernels, with a specific radius this analytical method generates density surfaces that show where the points are concentrated (Bailey and Gatrell, 1995). Bivariate Local Moran's I is an analytical tool that examines whether two characteristics are spatially correlated. With bivariate local Moran's I, we can identify the degree of such a correlation in the four categories: first, High–High where both values of the variables are high; second, Low–Low where both are low; and Low–High and High–Low where only one is high, while the other is low. Moran's I index of 1 and -1 represents the perfect positive and negative correlation between the two variables, respectively, with values close to zero implying weak correlations. The absolute value of .3 or higher is considered a fairly strong correlation (Yoon and Srinivasan, 2014).

3. Analytical design

3.1. Study site

Our study site consists of 80 Silver Zones in Seoul, South Korea. Assuming that the effect of the Silver Zone may extend beyond this immediate area, we include 300-metre buffers around the zones themselves, which implies an average of a 5-minute walking distance (Azmi et al., 2012). For the DID analysis, we analysed 58 zones established either from 2007 to 2009 or from 2011 and 2014. For the DID analysis with the environmental factors, we excluded zones that had no collision incidence and analysed the rest 27 zones. For the spatial analyses, 32 zones established from 2011 to 2015 were considered. Fig. 1 describes our study area.

3.2. Dataset and sample

The two primary datasets were Silver Zone data collected by the Seoul Metropolitan Government from 2007 to 2014 and Elderly Pedestrian Vehicular Collision data from the Korea Road Traffic Authority (KoRoad) from 2010 to 2015. The Silver Zone data include locations, configurations and installation dates of each Silver Zone, and the name and type of facilities that it centres on. The Elderly Pedestrian Vehicular Collision dataset provides detailed information on collisions, including locations, dates, times, the age and gender of the injured party and driver, seriousness of the injury/damages, road types and the weather at the time of the incident. The number of elderly pedestrians injured in vehicular collisions totals 3009, with 478 occurring in 2010, 390 in 2011, 549 in 2012, 564 in 2013, 711 in 2014 and 668 in 2015.

For the supplementary information about the physical environments of the zones, we used Daum, a web portal that provides eye-level maps, satellite imageries and street views. We included nine different characteristics: distance from the centre of Silver Zone, percentage of coloured road surface in the entire Silver Zone, the number of lanes, distance from a collision to the nearest crosswalk, speed bump and traffic light, presence and location of fencing, no-sidewalk road signage and land use (e.g., residential and commercial). The descriptive statistics is in Appendix I.

4. Analytical plan

4.1. Difference-in-Difference

With DID approach, we compare the count of collisions in the treatment and control groups before and after their designation as Silver Zones. Our treatment group comprises collisions that occurred in the areas designated as Silver Zones and the 300-metre buffer area in 2011, 2012, 2013 or 2014. Our control group is the collision count in the areas that were designated as Silver Zones and the 300-metre buffer areas in 2007, 2008 or 2009. Control group is supposed to be a group of samples that are closely matched with treatment group, whereby the only difference is whether the treatment was imposed or not. Therefore, the areas designated as a Silver Zone in the earlier years can be a more appropriate control group for the areas designated as such in the later years, than the randomly selected, non-Silver Zone areas. To allow for a

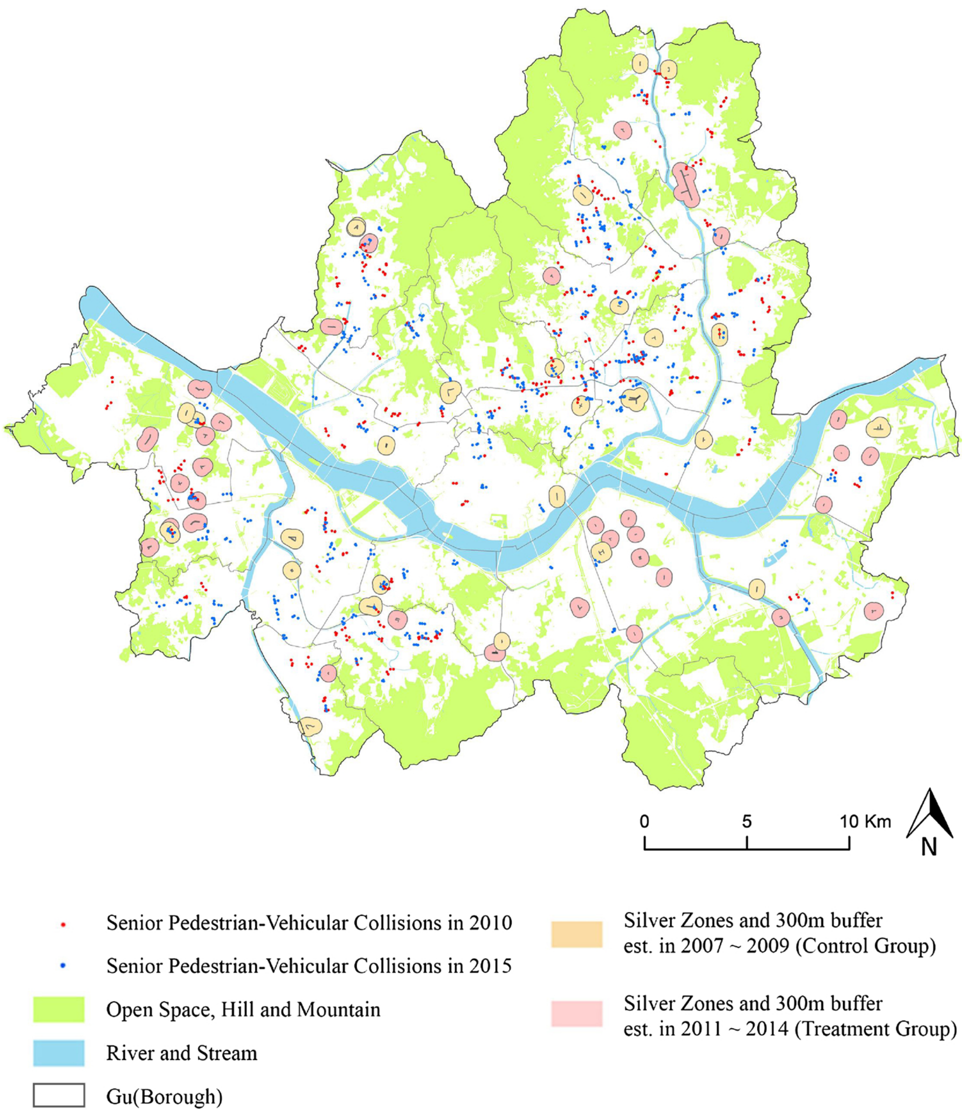

Fig. 1. Study Site: Seoul, South Korea.

1-year stabilisation period, and to measure the full-year effects of those Silver Zones, the collisions were counted in the year 2010 for the before condition and during 2015 for the after condition.

If the Silver Zone designation improved pedestrian safety, the number of collisions would go down more or show less of an increase from 2010 to 2015 in the treatment group, compared with the number counted in the control group. Since new Silver Zones are advertised to be safer and easier to walk, it has potential to attract more pedestrians. If this were the case, pedestrian collisions would have impacted by the increased exposure. To rule out this possibility, we conducted two sets of *t*-tests to verify whether the changes of the pedestrian volume differ or not in the two groups (control and treatment groups), in the two points of the collision measurement. Due to data availability, we used data of 2009 and 2015. We could conclude that the treatment and control groups have maintained the same level of senior pedestrians in both years, and the level of change between those two years in those two groups are identical. This implies that the exposure of the senior pedestrians to collisions have changed in a similar way in both of the groups. The result of the *t*-test is available from the authors upon request.

The full DID model is shown below:

$$g(E(Num\_Collision_i)) = \beta_0 + \beta_1 Treatment_i + \beta_2 After_i + \beta_3(Treatment_i\_After_i) + \boldsymbol{\beta X_i}$$

Function (1) Difference in Differences (DID) model

Our dependent variable, *Num_Collision*, is the number of collisions occurred in the each Silver Zone in the aforementioned years (mean: 0.83); *Treatment* is a binary variable indicating whether the collision occurred within the treatment group or the control group ($Treatment = 1$ if established in 2011, 2012, 2013 and 2014 or $Treatment = 0$ if established in 2007, 2008 and 2009). *After* is a binary variable indicating whether the collision occurred in 2015 or in 2010 ($After = 1$ if occurred in 2015 or $After = 0$ if occurred in 2010). By including the interaction term, *Treatment_After*, as a product of the group and time indicator, we allow differential changes from the before and after periods in the number of pedestrian-vehicular collisions between those two groups. $\boldsymbol{\beta X_i}$ is a vector of the aforementioned environmental characteristics of the Silver Zone. The detailed explanation of the variables is in Appendix I.

We fit the ZIP, ZINB, ZTP and ZTNB models: first, ZIP and ZINB with the three aforementioned variables directly relevant to the DID inference, and then ZTP and ZTNB with all other additional variables representing environmental characteristics of the Silver Zone. In the first analysis, all Silver Zone samples are included, and many of them have not accommodated any collision in either 2010 or 2015. Due to the high frequency of zero value, ZIP and ZINB are utilized to handle the data. In the second analysis, on the other hand, the data is zero truncated because the Silver Zones with collision records are included in the sample. ZTP and ZTNB are utilized to address the zero truncated characteristic of the data.

g(.) is a link function that relates the expected dependent variable to the linear predictors (Fox, 2016). For the Poisson and negative binomial family, a canonical link function–natural log is used. Consequently, the relationship between the dependent and independent variables in Poisson, negative binomial models are shown below:

$$ln(E(Num\_Collision_i)) = \beta_0 + \beta_1 Treatment_i + \beta_2 After_i + \beta_3 (Treatment_i\_After_i) + \boldsymbol{\beta X_i}$$

Function (2) Poisson model

For the negative binomial model, as its variance is allowed to differ from the mean, a latent heterogeneity term ε_i is introduced in the conditional mean of the model, where $\exp(\varepsilon_i)$ follows gamma distribution (Shankar et al., 1995):

$$ln(E(Num\_Collision_i)) = \beta_0 + \beta_1 Treatment_i + \beta_2 After_i + \beta_3 (Treatment_i\_After_i) + \boldsymbol{\beta X_i} + \varepsilon_i$$

Function (3) Negative binomial model

4.2. Spatial analysis

We use two spatial analyses, Kernel Density Estimation (KDE) and Bivariate Local Moran's I, to further investigate the geographical relationship between Silver Zones and sites with a high occurrence of senior pedestrian car-related collisions, and to determine whether the collision points and Silver Zone locations overlap.

First, we plotted a series of KDE maps to visualise the locations of the new Silver Zones established in each year from 2011 to 2015, and the locations of frequent senior pedestrian car-related collisions in the prior year. If the Silver Zones were established close to the previous year's sites of highest-frequency collisions, the maps should show a geographical match between them.

To achieve a more rigorous assessment of the degree of spatial match than a visual comparison can provide, we used the Bivariate Local Moran's I analysis. We created the two variables aggregated at the level of the census tract[6] to measure their correlation in this fashion: first, the cumulative number of senior pedestrian-vehicular collisions from 2010 to 2014, aggregated by census tract, and second, the total number of Silver Zones in the same census tract as of 2015. The bivariate Local Moran's I function is presented below in Function (4):

$$I_i = A_i \times \sum_{j=1}^{n} \omega S_i$$

Function (4) Bivariate Local Moran's I A_i is the number of such collisions in the census tract i (up to n), S_i is the number of Silver Zones in the same census tract and ω is a spatial weight matrix. We chose a distance-based weight matrix over contiguity-based ones, since the analytical units vary in size and configuration, thus could not be consistent in defining neighbouring units. We used a threshold distance of 300 m because it represents an average 5-minute walking distance for elderly and could be considered a maximum distance seniors are willing to walk as part of their daily routine.

5. Findings

5.1. Result 1: DID

In Table 1, we present the analytical results of the ZIP, ZINB, ZTP and ZTNB regression.

For the first DID analysis, in order to select the best model for testing the effects of Silver Zone, we conducted two steps of tests; first, we tested zero-inflation with Vuong test to select a model between standard Poisson and ZIP models, and second, we tested overdispersion with a likelihood ratio test to select a model between ZIP and ZINB model (Desmarais and Harden, 2013; Zuur et al., 2009). The Vuong test statistics were significantly positive ($z = 6.64$, $Pr > z = 0.00$), led us to ZIP over the standard Poisson model. The likelihood ratio test indicates overdispersion, led us to ZIP over ZINB model. Therefore, we selected ZIP as the final model. Also, smaller AIC for ZIP reaffirmed our decision.

For the second DID analysis, since we excluded all Silver Zones that had no collision history in 2010 or 2015, the data became zero-truncated. To select between ZTP and ZTNB model, we again used the likelihood ratio test and confirmed that our data is not overdispersed, consequently, we selected ZTP as our final model.

From both the ZIP and ZINB models, we learned that the Silver Zone is ineffective in reducing collisions. All variables directly relevant to DID - *After, Treatment* and their interaction, *After_Treatment* - explain that the change in the number of collisions in the treatment and control groups from the before and after period is not different at 5% significance level.

Among other environmental factors, the *Locational range*–a binary variable indicating whether a collision happened in the Silver Zone, *Distance to traffic lights, Distance to crosswalk* and *Distance to intersections* are demonstrated to be a predictor of senior pedestrian collisions.

First, we found that senior pedestrian collisions are more likely to occur in the Silver Zone compared to their 300-m buffer. The expected number of collisions in the Silver zone is 684% ($=\exp(1.923)$) of that of the 300-m buffered area. The Silver Zone is established in front of senior care facilities where senior pedestrians tend to concentrate, and the chance of collision involving them would increase. In addition, the variable *Distance to traffic lights* suggests that more collisions would occur in locations farther from vehicle traffic lights. When moving 10 m away from the vehicle traffic light, the expected number of collisions is increased by 109.86% ($=\exp(0.094)$) of that of otherwise cases. Longer distance of traffic intervals may encourage drivers to drive faster and also encourage pedestrians to jaywalk.

Distance to crosswalks is also a factor related to the number of senior pedestrian-vehicular collisions. When moving 10 m away from crosswalks, the expected number of collisions is reduced to 88% ($=\exp(-0.117)$) of that of the otherwise cases, holding all other variables constant. This means that collisions have occurred more frequently near crosswalks. This result may imply that the areas near crosswalks are relatively unsafe for senior pedestrians due to drivers' frequent violation of traffic signals or their tendency to make sudden stops. However, it could also be true that simply a higher density of pedestrians is exposed to collisions near crosswalks. The variable *Distance to intersections* can be understood in a similar manner: intersections are also collision-prone spots (Lee and Abdel-Aty, 2005; Lee et al., 2017; Miranda-Moreno et al., 2011). When moving 10 m away from intersections, the expected number of collisions is reduced to 97% ($=\exp(-0.028)$) of that of the otherwise cases. In intersections with vehicles coming from many different directions, the chance of collisions naturally increases: where cars make multi-directional turns simultaneously, drivers tend to pay less attention to pedestrians. As mentioned above, it is also possible that increased exposure of the pedestrians in the intersections or crosswalks could have impacted on change in the number of collisions.

[6] In South Korea, the census unit is equivalent to the census tract in the U.S. It is called *Jigyegu*, and contains approximately 500 residents.

Table 1
Parameter estimates, standard errors and approximate p-values from the ZIP, ZINB, ZTP and ZTNB models, describing the DID relationships between the number of collisions in treatment and control groups in the before and after period, along with other selected predictors.

	Effects of Silver Zone				Effects of Silver Zone and Physical Elements associated with Senior Pedestrian Collisions	
	Zero Inflated Poisson Model		Zero Inflated Negative Binomial Model		Zero Truncated Poisson Model	Zero Truncated Negative Binomial Model
Variables	ZIP with DID	inflate	ZINB with DID	inflate	ZTP with DID and Physical Variables	ZTNB with DID and Physical Variables
After	0.265 (0.292)	−0.287 (0.607)	0.265 (0.292)	−0.287 (0.607)	0.202 (0.390)	0.202 (0.390)
Treatment	0.233 (0.368)	1.200* (0.698)	0.233 (0.368)	1.200* (0.698)	0.241 (0.615)	0.241 (0.615)
After_Treatment	0.032 (0.461)	0.055 (0.947)	0.032 (0.461)	0.055 (0.947)	0.082 (0.472)	0.082 (0.472)
Loc_range	–	–	–	–	1.923** (0.757)	1.923** (0.757)
Percent_colour	–	–	–	–	0.611 (0.685)	0.611 (0.685)
Number_lane	–	–	–	–	0.371 (0.236)	0.371 (0.236)
Dist_crosswalk	–	–	–	–	−0.117** (0.054)	−0.117** (0.054)
Dist_light	–	–	–	–	0.094*** (0.032)	0.094*** (0.032)
Fence	–	–	–	–	−0.658 (0.479)	−0.658 (0.479)
Dist_intersection	–	–	–	–	−0.028** (0.0133)	−0.028** (0.0133)
Speedlimit Signage	–	–	–	–	−0.0675 (0.335)	−0.0675 (0.335)
No_sidewalk	–	–	–	–	0.404 (0.896)	0.404 (0.896)
Residential	–	–	–	–	−0.709 (0.786)	−0.709 (0.786)
Commercial	–	–	–	–	0.248 (0.427)	0.248 (0.427)
Constant	0.985*** (0.233)	0.706 (0.445)	0.985*** (0.233)	0.706 (0.445)	−0.050 (0.952)	−0.050 (0.952)
Observations	116	116	116	116	27	27
−2LL	−0.0264		−0.0264		−0.2345	−0.8303
df	8		9		15	15
AIC	230.4553		232.455		117.868	117.868
BIC	252.484		257.238		137.306	137.306
Prob > chi2	0.4160		0.4160		0.0404	0.6987

Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5.2. Result 2: Spatial analysis with kernel density and bivariate local Moran's I

From the Kernel Density maps, we found no apparent relationship between the locations of higher numbers of senior pedestrian collisions in a given year and the locations of newly established Silver Zones in the next year. In general, no spatial match is visible except for some small areas. For example, the northwestern area in Fig. 2(a), and the south western parts in Fig. 2(c), (d), (e) whereby Silver Zones seem to have been inaugurated at sites of higher collision frequency in the

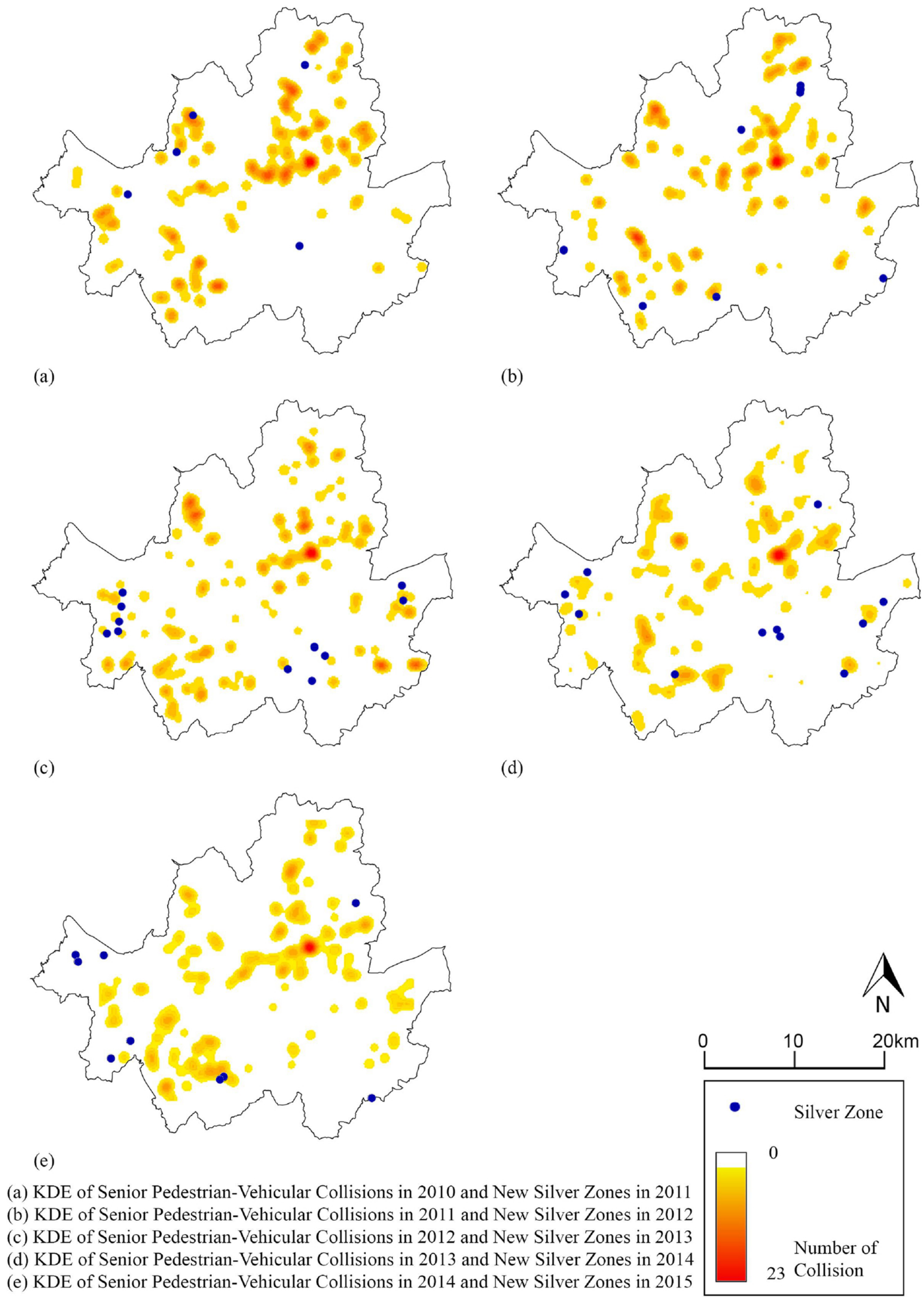

Fig. 2. Kernel Density Estimation of Senior Pedestrian-Vehicular Collisions and New Silver Zones.

previous years.

From the Bivariate Local Moran's I analysis, we found a similar result as above. The bivariate local Moran's I value of -0.004 (p = 0.05) implies very little negative or no correlation between the density of senior pedestrian-vehicular collisions and Silver Zone locations (Fig. 3). If Silver Zones had been established where such collisions were the most prevalent, then the areas marked as High–High and Low–Low should be dominant in the map. In our analysis, only 50 are marked as High–High and 1062 are marked as Low–Low out of a total of 16,230 census tracts in Seoul. Indeed, there is a higher occurrence of spatial mismatch: 1,221 are marked as High–Low, meaning Silver Zones were not established at sites that coincided with a higher number of collisions; and 634 were marked as Low–High, meaning the opposite, that Silver Zones were implemented in areas with low rates of elderly pedestrian-vehicular collisions.

We should note that there is a chance of misreading this result as the real effects of the system. If Silver Zones actually reduce the number of collisions, then the census tracts with a higher number of Silver Zones would have fewer collisions, and thus be categorised as Low–High. Therefore, the large number of census tracts in this category presented in our bivariate local Moran's I result could be read as supporting the effectiveness of the Silver Zone system. However, through our carefully designed quasi-experiment, the Difference-in-Difference analysis and the Kernel Density map, we previously demonstrated the ineffectiveness of the Silver Zone system and therefore eliminate the other interpretation of this analytical result.

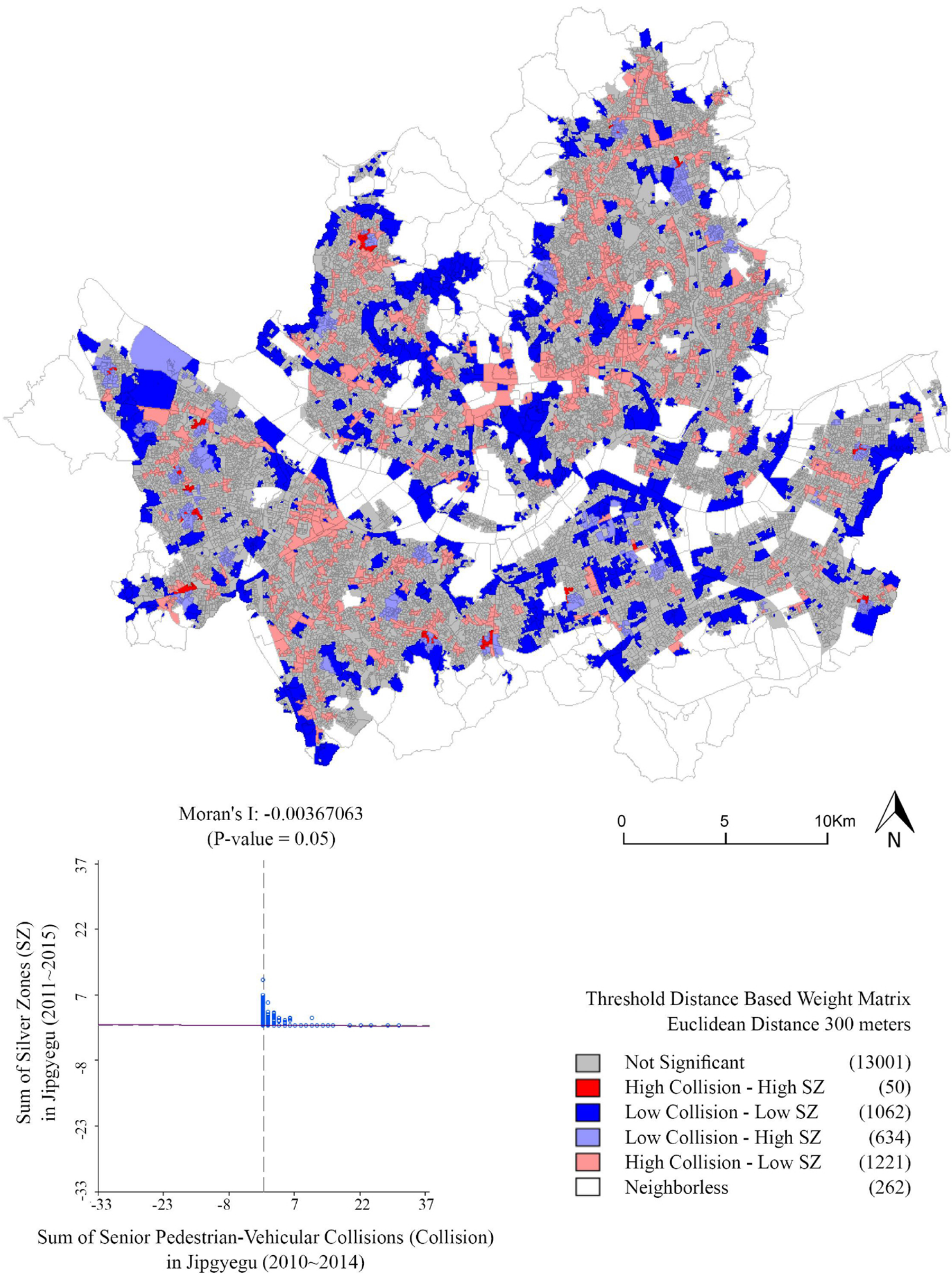

Fig. 3. Bivariate Local Moran's I Cluster Map (Threshold 300).

6. Conclusion

In this study, we investigate the effectiveness of the Silver Zone in two respects. First, we assess the changes in the number of elderly pedestrian-vehicular collisions in the two groups through the DID approach, and second, we assess the appropriateness of their locations to address highly collision-prone spots through spatial modelling.

As discussed above, our statistical analyses demonstrate that the Silver Zone, as currently implemented, is an ineffective measure in reducing senior pedestrian-vehicular collisions. The number of collisions increased from 2010 to 2015 without statistical difference in both treatment and control areas; in other words, the Difference-in-Difference was not supported at a statistically significant level. The analysis also highlights which types of physical characteristics contribute to senior pedestrian collisions. Areas bounded as a Silver Zone have more collisions than their 300-metre buffers. In addition, areas farther away from traffic lights and areas closer to crosswalks or intersections invite more of such collisions.

Our analytical results also suggest that current Silver Zone locations do not spatially coincide with areas of higher senior pedestrian-vehicular collisions. The Kernel Density Estimation of senior pedestrian collision density shows that yearly records of such collisions are not closely reflected in new Silver Zone designations the following year. The Bivariate Local Moran's I analysis provides similar results in that the cumulative number of collisions do not overlap with designated Silver Zones. As mentioned in the background of this study, Silver Zones are initiated at the request of individual operators of senior facilities, without a city-level master planning process incorporating collision pattern studies (Ministry of Public Administration and Security, 2012). The current process creates several problems. On the one hand, the city government could easily overlook areas with high rates of elderly pedestrian-vehicular collisions were it not for the request of Silver Zone by the head of senior citizen facilities. Without a more comprehensive system, the city is not able to coordinate individually requested zone designations with other dangerous sites beyond the vicinity of senior facilities, such as the dangers of long distance of traffic intervals, identified above.

Although the system was originally conceived for seniors, Silver Zones could be used for greater pedestrian safety for all age groups. However, for this system to function effectively, a more comprehensive approach is needed, both for locating these special zones and designing their safety measures. Instead of leaving it to civil petition, the city government should take responsibility for inventorying pedestrian collisions, including locations, through periodic surveys. Based on this information they should prioritise the most critical sites for Silver Zone designation. Moreover, in addition to the signage and road marking that currently comprises the system, other design features and measures could be integrated into the system, such as longer green lights for slow pedestrians, fences to prevent jaywalking, high friction pavement, speed cameras, in-roadway warning flashing light (IRWL) systems to slow the speed of vehicles and part-time pedestrianization (Park et al., 2010; Abdelrahman et al., 2011; Zhang and Ma, 2014; Castillo-Manzano et al., 2014).

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aap.2018.07.005.

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