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The transportation safety of elderly pedestrians: Modeling contributing factors to elderly pedestrian collisions

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ABSTRACT

For the elderly, walking is an important, reliable mobility option, since the elderly frequently lose their physical and/or sensory ability to drive as their age increases. However, elderly pedestrians are vulnerable on the streets and are at great risk of injury or death, when involved in a collision. This is due to not only increased frailty but also such issues as reaction speed and confidence on the streets. Therefore, pedestrian safety for older adults is a growing concern. This paper comprehensively examines the relationship between physical conditions and elderly pedestrian safety at the intersection level. By constructing a multinomial logistic regression (MLR) model, this paper identifies the exclusive contributing factors to elderly pedestrian collisions rather than younger pedestrian collisions. The outputs from the model suggest that facilities such as raised median, three-way intersection, street tree, and park and recreational land use improve the safety of elderly pedestrians. They also imply that bus stops increase elderly pedestrian collisions, while the intersections with crosswalks or colored crosswalks do not contribute to elderly pedestrians' safety, but the safety of younger pedestrians. The findings of this paper provide insight to transportation policies like Complete Street and Vision Zero and help to improve the current road system that are designed for automobiles and young, healthy road users.

1. Introduction

The aging of population is one of the most significant demographic trends in the history of the United States. In 2050, the population aged 65 and over is projected to be 83.7 million, almost double its estimated population of 43.1 million in 2012 (Mather et al., 2015). With the growing elderly population, living and working environments must be designed to meet the needs of the aging population. As people age, walking becomes critically important in maintaining their mobility. While vehicles are the primary mode for the elderly, walking is the second most relied upon mode of transportation for the elderly (Bailey et al., 1992). It is inevitable for the elderly to lose their physical and/or sensory ability to drive, as their age increases. Therefore, the elderly depend more heavily on walking as a means of mobility. Walking is vital to the mobility of the elderly, not only to carry out essential daily tasks, but also to maintain social contacts and exercise.

Safe pedestrian travel, therefore, becomes very important for older adults. However, unsafe roads are a significant barrier to the promotion of the elderly's pedestrian activities. Elderly pedestrians are a vulnerable road user group and are at great risk of injury or death, when involved in a collision (Thomas et al., 2018). In 2015, about 10,000 elderly pedestrians (65 years and older) were killed or injured in traffic collisions (National Highway Traffic Safety Administration (NHTSA), 2017). The fatalities of elderly pedestrians have become an especially critical problem. While the elderly account for 14.8 percent of U.S. population, 18.6 percent (1002 out of 5376) of fatal pedestrian collisions involved elderly pedestrians in 2015. Elderly pedestrians have increasingly become the victim of collisions. They have an increased risk of fatality, due to not only increased frailty but also issues, such as reaction speed and confidence on the streets.

While a large volume of research has paid attention to the safety of elderly drivers, there has been lack of research that addresses the safety of elderly pedestrians. Some studies have examined elderly pedestrians' age-related functional changes and health issues, such as dementia, in association with their pedestrian fatalities (Oxley et al., 2007; Gorriea et al., 2008). Some research has addressed elderly pedestrians' behavioral factors, especially walking pace when crossing the street, from the perspective of pedestrian safety (Oxley et al., 1997; Carmeli et al., 2000; Dommes et al., 2012). The research found that older pedestrians take a longer amount of time to cross a road than younger pedestrians do. They also crossed more frequently, when they was closer to moving traffic and generally adopted less safe road crossing strategies than their younger counterparts, due to declines in their physical, sensory, perceptual or cognitive abilities.

The current road system, which is mainly designed for vehicles and for young, fit and healthy road users, makes older adults vulnerable on

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the streets. Higher driving speeds that reduce predictability and reaction times of pedestrians become a major challenge for elderly pedestrians and are likely to increase their fatalities and severe injuries (Davis, 1773). Complex roadway conditions also pose many dangers for elderly pedestrians. They include complex intersections, high traffic volumes, and wide, multi-lane roads (Staplin et al., 2001; Organization for Economic Co-operation and Development (OECD), 2001). While poor visibility of signs and the presence of center turning lanes contribute to elderly pedestrian collisions, frequent traffic signals and marked crosswalks reduce the collisions (Shankar et al., 2006). Elderly pedestrians are especially over- represented in intersection collisions, since they demand efficient cognitive processing, fast responses and quick actions. (Abou-Raya and El Meguid, 2009; Oxley et al., 2007; Zegeer et al., 1993). In 2015, 52.8 percent of elderly pedestrian collisions occurred at intersections, while intersection collisions account for 43.9 percent of younger pedestrian collision (NHTSA, 2017).

The purpose of this paper is to comprehensively examine the relationship between the physical conditions of the urban environment and elderly pedestrian safety at the intersection level. Little research has addressed the influence of other aspects of the physical urban environment, other than roadway characteristics on elderly pedestrian collisions. Focusing on elderly pedestrian collisions at intersections in the County of Los Angeles, this paper analyzes elderly pedestrian collisions in association with a wide range of built environment. This includes not only intersection characteristics but also ambient conditions and land use patterns around intersections. This paper also sheds light on the heteroscedasticity of pedestrian age. Although it can be hypothesized that the relationship between pedestrian collisions and physical conditions may vary by pedestrian age (Kim et al., 2008), there has been a lack of research that addresses how the physical environment influences different age groups of pedestrians. Considering this underestimation, this paper attempts to compare the contributing factors to elderly pedestrian collisions, with those of younger pedestrian collisions by constructing a multi-nominal logistic regression model. This model allows the identification of the factors that exclusively influence elderly pedestrian collisions and that distinctly associate elderly pedestrian collisions from younger pedestrian collisions.

2. Research method

The geographical context of this paper is the County of Los Angeles, California. This study area can serve as an exemplary case study for many metropolitan areas in the U.S. Like any metropolitan cities, pedestrian are the most vulnerable users of the streets in Los Angeles County. Automobile oriented culture and roadway system in the area make pedestrians, especially elderly pedestrians, more vulnerable. In the City of Los Angeles, two-third of older adults killed were walking (City of Los Angeles, 2018).

This paper takes into consideration intersections as the unit of analysis since pedestrians' crossing roadway commonly occurs at intersections (Blackburn et al., 2017, 2018). It focuses on the intersection on primarily and arterial roads by excluding highways and expressways, since pedestrian traffic is prohibited on those roads. Due to the limited number of collisions that occurred on local roads, this paper also excludes the intersections on local roads. Using the intersection as the unit of analysis, this paper aggregates pedestrian collisions by intersection. Pedestrian collisions that occurred within 300 feet of the intersection were identified as intersection collisions. The distance of 300 feet indicates the stopping sight distance (SSD). This is the distance that permits drivers to anticipate and avoid potential collisions. On a road, which has an average speed of 40 miles per hour, a collision can be avoided within this distance (American Association of State Highway and Transportation Officials (AASHTO), 2004).

The collisions was measured using three years (2015 to 2017) of the statewide integrated traffic records system (SWITRS)'s collision record data. The SWITRS is a database that serves as a means to collect and process data gathered from a collision scene by California Highway Patrol (CHP) staff and members of its allied agencies. According to the SWITRS data, there were 14,926 pedestrian collisions that occurred during this period within the study area. The number of collisions defined as intersection collisions totaled 13,844, which is equivalent to about 92.8 percent of the total pedestrian collisions in the county. They include 2471 and 11,373 elderly and younger pedestrian collisions, respectively. Of 80,108 intersections in the study area, 2222 and 8415 intersections have at least one elderly and one younger pedestrian collision, respectively.

This paper employs multinomial logistic (MNL) regression to examine a nominal dependent variable, given one or more independent variables. Since the dependent variable is a categorical variable that represents pedestrian collisions by age group, a MNL model is an appropriate analysis method for this project. This paper defines the nominal dependent variable of the MNL model, by categorizing the intersection by the frequency of collisions that two age groups, elderly and younger pedestrians, are involved in. An elderly pedestrian collision is defined as a collision in which a pedestrian age 65 and over is involved. Younger pedestrian collisions involve collisions of pedestrians who are younger than 65 years. As a reference category, this paper adds intersections where pedestrian collisions did not occur. Thus, this paper coded three categories as shown below and used them as the dependent variable for the MNL model.

0 = intersections with no pedestrian collisions (called "INC"),

1 = intersections with a high concentration of elderly pedestrian collisions (called
"IEC"), and

2 = intersections with a high concentration of younger pedestrian collisions (called
"IYC")

This MLR approach is introduced in Eqs. (1) through (4).

$$\mathrm{Prob}(\ y=\mathrm{INC})\ =\frac{e^{U_{INC}}}{e^{U_{INC}}+e^{U_{IEC}}+e^{U_{IYC}}}$$
$$\mathrm{Prob}(\ y=\mathrm{IEC})\ =\frac{e^{U_{IEC}}}{e^{U_{INC}}+e^{U_{IEC}}+e^{U_{IYC}}} \tag{1}$$
$$\mathrm{Prob}(\ y=\mathrm{IYC})\ =\frac{e^{U_{IYC}}}{e^{U_{INC}}+e^{U_{IEC}}+e^{U_{IYC}}}$$

Applying the MLR model requires calculation of the intersections dominated by the collision of the age groups, which is proportional to the sum of all the intersections. That is, where Uj is the utility function of j intersection by age groups; j = elderly pedestrian collision (IEC), younger pedestrian collision (IYC), or no dominant collision (INC).

$$\text{Also, } log\left[\frac{Prob\ (y=j)}{Prob\ (y=INC)}\right]=\sum\nolimits_i \beta_i^j X_i \tag{2}$$

where j = IEC or IYC, and

i = independent variables, X, affecting the dominant collision age groups.

Eq. (2) connects the log-transformed odds ratio for an age group of collision j in the left-hand side to the product of the parameters and independent variables as a linear structure. Hence, by introducing a multinomial logit link function defined as

$$g^j(x)=\sum\nolimits_i \beta_i^j X_i = log\left[\frac{Prob\ (y=j)}{Prob\ (y=INC)}\right] \tag{3}$$

we can substitute the utility function of Uj with the multinomial logit link function gj(x) and combine the Eqs. (1) and (2). The utility function of the collision type is estimated in Eq. (4).

$$U_j(x)=\sum\nolimits_i \beta_i^j X_i \tag{4}$$

The predicted Uj(x) is added to calculate the probability of dominant age group in Eq. (1). Therefore, the MLR model will provide insight on the intersection characteristics and surrounding environment that contribute to frequent occurrences of pedestrian collisions by a particular age group.

2.1. Dependent variable

After measuring the number of elderly and younger pedestrian collisions that occurred at each intersection, this paper identified Census block-groups adjacent to each intersection and normalized the collision numbers by the population of the age groups. The American Community Survey (ACS) population by age data was used (2015 ACS 5-year estimates). It is desirable to measure collision rates with the number of pedestrian collisions per pedestrian counts, but this paper employs the population of the age groups as a proxy variable due to the lack of pedestrian volume data, especially pedestrian volume by the age groups. The normalized values represent the number of elderly or younger pedestrian collisions per 1000 elderly or younger people, respectively. This paper then computed the difference of two normalized values, by subtracting the normalized value of younger pedestrians from the one of elderly pedestrians. This calculation takes the following Eq. (5):

$$\left(\frac{Elderly\ Pedestian\ Collision\ Count}{Elderly\ Population}\times 1{,}000\right) - \left(\frac{Younger\ Pedestian\ Collision\ Count}{Younger\ Population}\times 1{,}000\right) \quad (5)$$

This calculation returns larger positive values for the intersections, where the normalized value of the elderly is higher than the normalized value of the younger and vice versa. The outputs of the calculation were plugged into the spatial statistic method, Getis-Ord Gi*. The Getis-Ord Gi* statistic identifies those clusters of geometries with values higher and lower in magnitude, than might be expected by random chance. The outputs of Getis-Ord Gi* analysis include a z score and a probability value for each intersection. The z score represents the statistical significance of clustering for a specified distance. The Getis-Ord Gi*model takes the following form, (6):

$$Getis - Ord\ Gi^{*} = \left(\frac{\sum_{j=1}^{n} W_{ij}Z_j}{\sum_{j=1}^{n} Z_j} - \frac{\bar{Z}\sum_{j=1}^{n} W_{ij}}{n-1}\right)/\sqrt{S^2} \quad (6)$$

where: W_{ij} = Weight index by inverse distance
Zj = Attribute value of feature j
$\bar{Z}$ = The mean of attribute values
S^2 = Variance of attribute values
n = total number of features

The cluster of the intersections with high positive values identified by Getis-Ord Gi* analysis indicates intersections where elderly pedestrian collisions primarily occurred (IEC). The cluster of the intersections with low negative values indicates intersections, where younger pedestrian collisions are highly concentrated ("IYC"). Throughout this analysis, 106 and 253 intersections are exclusively identified as "IEC" and "IYC", respectively (P-value $\leq$ 0.05). In addition, this paper randomly selected 500 intersections from the intersections that do not record any pedestrian collisions, as the reference category for the MNL model (Fig. 1).

2.2. Independent variables

In order to construct the MNL model, this paper measured the characteristics of the selected intersections, as well as the land use of surrounding areas. They are identified as important pedestrian crash risk factors (Thomas et al., 2018). They are classified into the three broad categories; Intersection Characteristic, Ambient Condition, and Land Use Factor (Table 1).

The variables under the category of Intersection Characteristic represent a wide range of facilities and amenities that depict the conditions of the intersection. These variables attempt to measure the safety concerns of elderly pedestrians during the time that they cross roads. This paper collected all of the variables through a virtual observation using Google Maps Street View. For the observation, this paper virtually visited every intersection in the Google Maps Street View, observed the characteristics of the intersection and manually recorded the variables.

The variables under the category of Ambient Condition incorporate the surrounding conditions of the intersection that potentially influence elderly pedestrian collisions. The variables include factors associated with automobile traffic and flow around the intersection (e.g. VMT and bus stops), facilities where automobiles possibly interfere with pedestrians (e.g. gas stations and parking lots), and general conditions of sidewalks (e.g. sidewalk condition and street trees). While two variables, sidewalks and gas station, were also collected through Google Maps Street View, a series of geo-spatial analysis is employed to measure the other variables under this category. The variable, ParkLt, was computed for a 300-foot buffer from the intersection, the same distance used for the definition of intersection collision. The variables, StTree and BusSt, measure the areas covered by tree canopy and shade and the number of bus stops along the roadways at the intersection, respectively, by employing a 50-foot buffer from the right of way of the roadways. The tree and parking lots data was acquired from Los Angeles Region Imagery Acquisition Consortium (LARIAC) Program, which is a data acquisition program for digital aerial imagery and Light Detection and Ranging (LiDAR) data. The data for VMT and bus stops was collected from Southern California Association of Governments (SCAG) and Los Angeles County Metropolitan Transportation Authority (LA Metro).

The variables under the category of Land Use Factor are for gauging the indirect relationship between land use patterns and elderly pedestrian collisions. These variables attempt to shed light on how the trip origins and destinations of elderly pedestrians are associated with their collisions. Using the parcel-based land use data acquired from SCAG, this paper measured the land use patterns within pedestrian catchment (0.25 miles) from the intersection.

It is noteworthy that automobile speed is an important variable, but not included in the analysis mainly because actual automobile speed data was not available. Alternatively, speed limit data can be the proxy data for automobile speed and was available. However, it was observed that speed limit does not appropriately reflect the actual automobile speed at intersection. For this reason, this paper does not include automobile speed into the list of the independent variables.

3. Results

Before conducting a MNL regression analysis, this paper summarizes the descriptive statistics for the variables (Table 2). Of the independent variables, the standard deviation of the variables under the category of Land Use Factor was relatively small, while bus stop (BusSt) and parking lot (ParkLt) presented a relatively large standard deviation. This implies that these two variables represent the variations of transportation infrastructure in the study area. Otherwise, the small standard deviations suggest the consistency of the variables in the study area.

Overall, the MNL model generated reasonably reliable results. The pseudo R-squared values from the MNL model present a strong model fit. The pseudo R square values indicate that the outputs of the MNL model are acceptable. The values of Cox and Snell and Nagelkerke, 0.424 and 0.502, present a reliable model fit, respectively. Since the values of McFadden from 0.2 to 0.4 are considered highly satisfactory, the MNL model with 0.296 of McFadden presents a strong model fit. The value of -2 log likelihood from the MNL model (1128.351) also suggests a consistent, strong model fit.

Of the seventeen independent variables, three variables, Sigzd, VMT, and GasSta, present a statistically significant correlation with

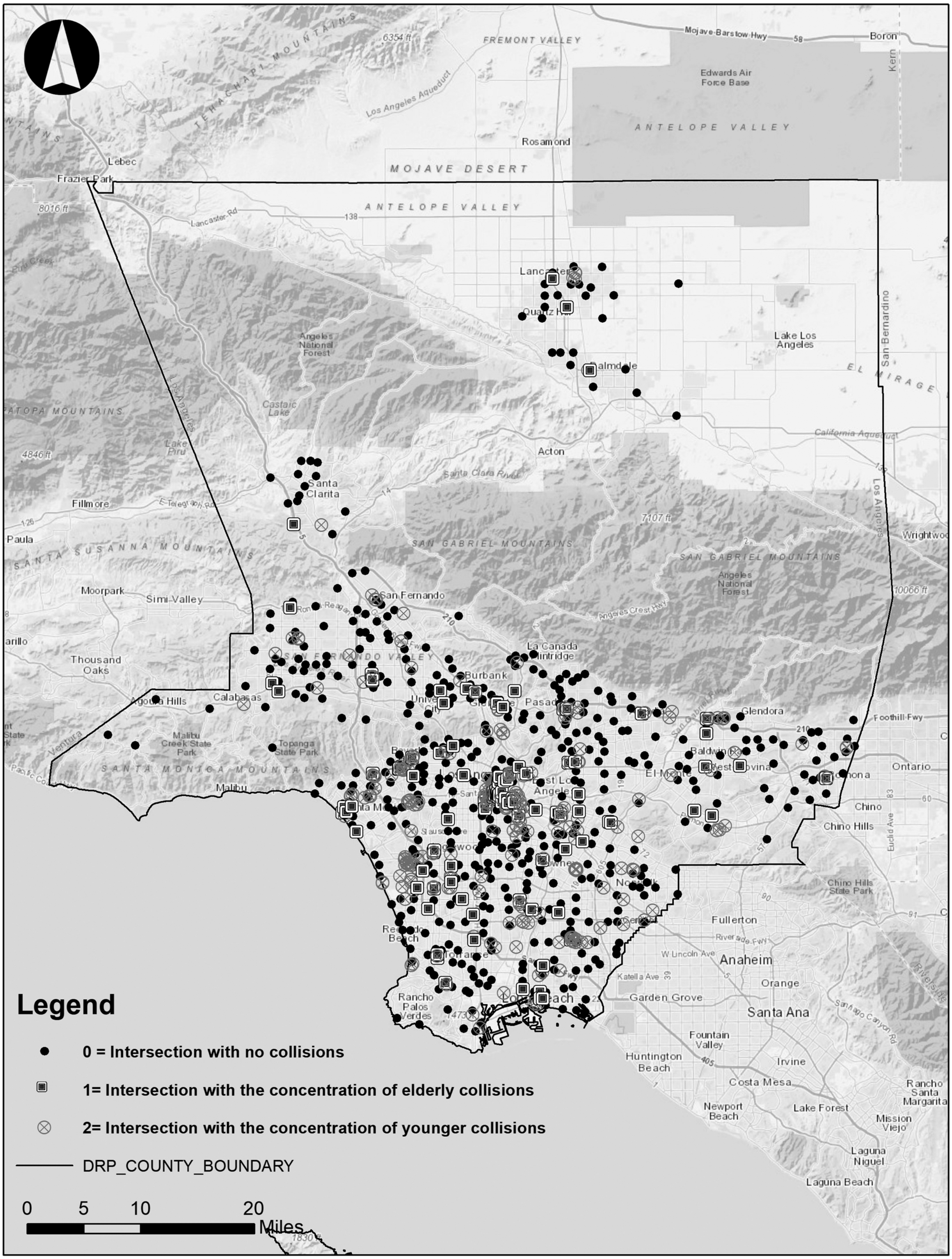

Fig. 1. The Categories of the Dependent Variable.

neither "intersections with a high concentration of elderly pedestrian collisions (IEC)" nor "intersections with a high concentration of younger pedestrian collisions (IYC)" (Table 3). Six variables that present a consistent correlation with "IEC" and "IYC" suggest their influence on pedestrian safety, regardless of their age. They include PersRT, PrimeRd, SidWlk, ParkLt, Resi, Comerc, and Office. The relationship of seven variables with "IEC" is distinct from the one with "IYC". Therefore, it can be concluded that the variables uniquely contribute to the safety of elderly pedestrians, but not the safety of younger pedestrians. The variables are CrsWlk, RsdMed, TInter, CrsWlkImp, StTree, BusSt,

Table 1
The List of Independent Variables.

Name	Definition	Description
Intersection Characteristics		
Sigzd	Signalized intersection	Dummy (if all roadways are equipped with traffic signal = 1, otherwise = 0)
CrsWlk	Missing crosswalks	Dummy (if at least one segment of roadway misses crosswalk = 1, otherwise = 0)
PersRT	Permissive right turn lane and signal	Dummy (if at least one segment has permissive right turns = 1, otherwise = 0)
RsdMed	Raised median	Dummy (if at least two segments have a raised median = 1, otherwise = 0)
TInter	The type of intersection	Dummy (if intersection is a 3-way intersection = 1, otherwise = 0)
CrsWlkImp	Colored or decorative crosswalks	Dummy (if crosswalks have aesthetic treatments = 1, otherwise = 0)
PrimeRd	The lanes of the primary road at intersection	Dummy (if the number lanes of the primary road are five or above = 1, otherwise 0)
Ambient Condition		
SidWlk	Sidewalk availability	Dummy (if at least one segment of roadway misses sidewalks, otherwise 0)
VMT	Traffic volume at intersection	Average vehicle miles traveled (VMT) of the roadway segments at intersection
StTree	Street tree canopy and shade	The percent of the areas covered by tree canopy and shade (within a 50-foot buffer from right of way)
GasSta	The existence of a gas station at intersection	Dummy (if there is a gas station at intersection = 1, otherwise = 0)
ParkLt	Parking lot	The percent of the areas designated as parking lot (within a 300-foot buffer)
BusSt	Bus stop	The number of bus stops (within a 50-foot buffer from right of way)
Land Use Factor		
Resi	Residential land use	The percent of the areas designated as residential land uses (within a quarter mile buffer)
Comerc	Commercial land use	The percent of the areas designated as commercial land uses (within a quarter mile buffer)
Office	Office land use	The percent of the areas designated as office land uses (within a quarter mile buffer)
PrkRec	Park and recreational land use	The percent of the areas designated as park and recreational uses (within a quarter mile buffer)

Table 2
Descriptive Statistics of Independent Variables.

	Mean	Standard Deviation	Minimum	Maximum
Ambient Condition				
VMT	5698.22	6148.08	0.00	74212.06
StTree	0.05	0.05	0.00	0.37
ParkLt	0.18	0.51	0.00	13.82
BusSt	6.56	11.48	0.00	133.00
Land Use Factor				
Resi	0.23	0.22	0.00	0.93
Comerc	0.08	0.10	0.00	0.75
Office	0.04	0.06	0.00	0.48
PrkRec	0.02	0.05	0.00	0.63

Note: The dummy variables are not included in the descriptive statistics.

and PrkRec. Four of them are under the category of Intersection Characteristics, while two and one variables are under the categories of Ambient Condition and Land Use Factor, respectively.

4. Discussion

It is interesting to examine the dynamics of physical conditions at the intersection level, especially intersection characteristics, in relation to pedestrian collisions. Of the seven variables under the category of Intersection Characteristic, four variables' correlation with “intersections with a high concentration of elderly pedestrian collisions (IEC)” differs from their correlation with “intersections with a high concentration of younger pedestrian collisions (IYC)”. An intersection with raised medians is less likely to be an “IEC”. This finding is consistent with a study reporting that elderly pedestrians' crossing behavior is more safe and similar to that of younger pedestrians on one-way divided roads (Oxley et al., 1997). Raised medians can be exclusively beneficial for elderly pedestrians whose walking pace is slower than that of younger pedestrians. Elderly pedestrians safely catch their breath, take rest on a raised median, or use the raised median as a shelter in an emergency, when crossing the street.

Furthermore, the correlation between 3-way intersection and “IEC” is somewhat similar to the findings from the previous research, with the contribution of complex roadways and intersections to elderly pedestrian collisions (Staplin et al., 2001; OECD, 2001). The less complex configuration and traffic flow of 3-way intersections compared to 4-way intersections, probably plays a positive role in elderly pedestrian safety. Another unique feature of 3-way intersections is narrow secondary roads. 3-way intersections are typically formed at the junction between a major road and a minor road. Therefore, there is a lower probability for elderly pedestrians to cross a wide, major road at a 3-way intersection. For this reason, elderly pedestrians are less involved in collisions at 3-way intersections.

Of the variables under the Ambient Condition category, street trees (StTree) and bus stops (BusSt) with “IEC” present a correlation that differs from one with “IYC”. The higher the ratio of the areas covered by street trees and their shade, the less likely an intersection would become an “IEC”. It is observed that street trees can be an ambivalent factor in relation to pedestrian safety. Street trees can make a positive contribution to pedestrian safety, by protecting pedestrians from collisions and by providing pedestrians and drivers with a clear definition of roadways and sidewalks. At same time, street trees also become a visual obstacle that blocks the view of both drivers and pedestrians. The outputs of the MNL model imply that the positive aspects of street trees improve the safety of elderly pedestrians, rather than younger pedestrians' safety.

The outputs also suggest that bus stop is a factor that increases the probability of an intersection to be “IEC”. The movements of buses arriving at and leaving from bus stops create complex traffic flows. The movements of buses also often become the unexpected, sudden movements of the vehicles around them (Kim and Kim, 2015). These complex, unexpected traffic movements exclusively contribute to the pedestrian collisions of the elderly, who have relatively slower reaction times and weaker physical and cognition strength. The outputs provide important insights into the current transportation planning strategies, such as Complete Street. Complete Street is a planning approach that creates streets designed and operated to enable safe access for all users from drivers to transit users and from children to seniors. It is logical for Complete Street to expand public transit service for people like the elderly, who are losing physical and cognitional strength. However, bus transit service can become a dilemma from the perspective of elderly pedestrian safety, since bus transit becomes a contributing factor to their collisions.

Table 3
The Outputs of Multinomial Logistic Regression.

	Intersections with a high concentration of elderly pedestrian collisions (IEC)				Intersections with a high concentration of younger pedestrian collisions (IYC)			
	B	Wald	Sig.	Exp(B)	B	Wald	Sig.	Exp(B)
Intercept	−0.504	0.458	0.499		−2.017	4.758	0.029	
Intersection Characteristics								
Sigzd	0.369	1.573	0.210	1.447	−0.400	1.245	0.265	0.670
CrsWlk	0.085	0.081	0.776	1.089	0.746	4.247	**0.039	2.109
PersRT	−1.092	14.370	***0.000	0.336	−0.653	3.498	*0.061	0.520
RsdMed	−0.723	9.256	***0.002	0.485	0.466	2.512	0.113	1.594
TInter	−0.854	10.645	***0.001	0.426	−0.314	0.962	0.327	0.730
CrsWlkImp	−0.079	0.034	0.854	0.924	−0.867	3.595	*0.058	0.420
PrimeRd	0.622	6.995	***0.008	1.863	0.695	5.805	*0.016	2.004
Ambient Condition								
SidWlk	0.500	2.785	*0.095	1.648	1.047	5.950	**0.015	2.850
VMT	0.000	0.804	0.370	1.000	0.000	0.829	0.363	1.000
StTree	−5.571	3.495	*0.062	0.004	−5.239	1.942	0.163	0.005
GasSta	−0.150	0.201	0.654	0.861	0.555	1.379	0.240	1.742
ParkLt	3.314	15.711	***0.000	27.502	3.401	16.357	***0.000	29.986
BusSt	0.020	3.856	**0.050	1.020	0.018	2.611	0.106	1.019
Land Use Factor								
Resi	−6.707	88.989	***0.000	0.001	−5.376	36.982	***0.000	0.005
Comerc	5.461	19.847	***0.000	235.238	7.249	28.688	***0.000	1406.035
Office	8.495	20.663	***0.000	4890.938	8.247	14.973	***0.000	3815.351
PrkRec	−6.683	5.052	**0.025	0.001	−5.751	2.409	0.121	0.003

Note: *, **, *** Correlations are significant at the 0.10, 0.05, and 0.01 levels, respectively.
The reference category is intersections with no pedestrian collision (INC).

Surprisingly, the relationship of "IEC" to surrounding land use is quite similar to that of "IYC". It was expected that the elderly's pedestrian collisions may be closely associated with residential land use due to their lifestyle that geographically attaches to their residence, rather than work places and/or shopping. Similar to younger pedestrian collisions, however, the outputs suggest that the elderly pedestrians often get involved in collisions near non-residential land uses, such as commercial and office. The only land use type that shows a distinct relationship with "IEC" from "IYC" is park and recreation uses. The higher ratio of the areas designated as park and recreational uses, the less likely an intersection would become "IEC". This negative correlation probably reflects the fact that the elderly are less likely to utilize park and recreation facilities.

The features of crosswalks, including missed crosswalks (CrsWlk) and colored or decorative crosswalks (CrsWlkImp), associate only with "IYC". An intersection with crosswalks for all the segments or with treated crosswalks is less likely to be "IYC". In general, it is clear that the locations of uncontrolled pedestrian crossing correspond to higher pedestrian collision rates than controlled locations due to inadequate pedestrian crossing accommodations (Blackburn et al., 2017, 2018). While some studies suggested that colored crosswalks have their aesthetic values rather than a role in the reduction of pedestrian collisions (City of Minneapolis, 2017), a colored or decorative crosswalk can be expected to make for safer pedestrian/vehicle intersections, by clearly defining crosswalks, addressing conflicts at crossing locations, making crosswalks more visible, alerting pedestrians and motorists of the crossing, and increasing driver compliance (yielding to crossing pedestrians) at crosswalks (Blackburn et al., 2017; Thomas et al., 2018; Blackburn et al., 2018).

However, surprisingly, the outputs suggest that the impacts of crosswalks are limited to younger pedestrians' safety rather than improving the safety of elderly pedestrians. This seems to reflect the fact that elderly pedestrians are discouraged from crossing roads and avoid jaywalking at the intersections with missing crosswalks. Similarly, high-visibility crosswalks such as colored or decorative crosswalks only contribute to the reduction of younger pedestrian collisions. The outputs probably imply that elderly pedestrians who present slow reaction speeds cannot exploit the momentary time and space created by the alerting capacity of the crosswalk and driver compliance, while young, healthy pedestrians can sensitively react to the time and space.

This finding suggests that each user group (e.g. the elderly, the disabled, or children) differently interacts with and utilizes pedestrian facilities. This supports the heteroscedasticity of pedestrian age that hypothesizes the various relationships between pedestrian collisions and physical conditions by pedestrian age. In addition to the generic benefits of pedestrian facilities for pedestrian safety, therefore, it is important to analyze and specify the distinct contribution of pedestrian facilities to each road user group. For example, it is necessary for further studies to investigate the dynamics between the decorative crosswalks and road users, including pedestrians and drivers, rather than making a generic judgment that a decorative crosswalk contributes to pedestrian safety. In the same vein, it is also necessary to conduct research on the behavior of elderly pedestrians at the locations of uncontrolled pedestrian crossing in comparison with one of younger pedestrians.

5. Conclusion

This paper presents a systemic, comprehensive approach that identifies a variety of physical conditions at the intersection level influencing elderly pedestrian collisions. Before concluding, this paper emphasizes the limitation of the data employed for normalization. It would be ideal to normalize pedestrian collisions by pedestrian traffic volume, since pedestrian collision is a phenomenon associated with pedestrian traffic. However, due to the lack of pedestrian traffic volume data in the study area, this study was not able to include the volume data into this normalization process. For the same reason, this paper was not able to incorporate automobile speed into the analysis. Actual automobile speed at the moment of collision must be an important contributing factor to pedestrian collision, but actual automobile speed data was not available. Although roadway speed limit data was available and can be a proxy variable, this paper did not include the data due to the concern that speed limit does not properly represent automobile speed at the intersection.

Nevertheless, the outputs from the multinomial logistic regression analysis suggest that there are physical contributing factors at the intersection level to elderly pedestrian collisions distinctive from ones to younger pedestrian collisions. Raised medians, 3-way intersections, street trees, and park and recreational land use make only a positive contribution to the safety of elderly pedestrians, while bus stops increase the odds of an intersection with high concentration of elderly pedestrian collisions. The findings shed light on the program development of transportation policies, such as Complete Street, and Vision Zero from the perspective of elderly pedestrian safety.

Overall, Complete Street promotes the safety of vulnerable road users by implementing the design of streets for all road users as well as all transportation modes. Ironically, this planning strategy may cause conflict between older pedestrians and buses. Consequentially, the strategy can contribute to the collision of elderly pedestrians. Therefore, it is important for local governments and transit agencies to develop street designs that minimize the complexity of traffic flows around bus stops. It is also observed that Complete Street strategies tend to underestimate the role of raised medians in pedestrian safety. The strategies primarily emphasize the design features of sidewalks and crosswalks, but pay less attention to raised medians. However, the findings suggest that raised medians can be viable options for the improvement of elderly pedestrians' safety. Thus, it should be considered to fully incorporate raised medians into one of design features in Complete Street.

The findings also provide Vision Zero with considerable strategies for elderly pedestrian safety. Vision Zero is a traffic safety policy that aims to achieve a roadway system with no acceptable number of traffic deaths and/or serious injuries. Many cities in the U.S including City of Los Angeles adopted the policy. For example, the City of Los Angeles committed to the principle that prioritizes human life in the design and operation of the streets and set a goal to eliminate traffic deaths by 2025 (City of Los Angeles, 2018). This policy is an example of local governments' commitment to improve transportation safety. However, although senior pedestrians present the highest rate of fatality, there have been limited programs that exclusively target the improvement of elderly pedestrian safety (e.g. senior slow zone and safe routes for seniors). Reconfirming the positive aspects of the programs' overall directions, this paper provides insight on the articulation for the program development of the policy. This paper especially suggests the design features of pedestrian facilities that exclusively support the safety of elderly pedestrians. For example, high visibility crosswalks are one of the important pedestrian safety features, but one of the findings indicate that the current design of the crosswalks does not contribute to the safety of elderly pedestrians. Therefore, it is important to develop the colors and patterns for crosswalks that serve the elderly's perception and sensory level. Since it was also confirmed that street trees positively contribute to the improvement of elderly pedestrians' safety, it should be also considered to plant trees in senior slow zones and along safe routes for seniors.

In summary, transportation safety is currently one of the top transportation priorities in many local governments. A high percentage of the people killed on the streets are pedestrians and an alarming number of them are vulnerable road users, including children and older adults. Thus, it is important for local governments and transportation agencies to refurbish the current road system that is generally designed for young, healthy road users, that allows the dominant attitudes of drivers to neglect the rights of vulnerable pedestrians. Creating safe and friendly pedestrian environments not only for young, healthy road users, but also for older, vulnerable pedestrians will truly contribute towards more healthy and sustainable communities by promoting active lifestyles and social interaction.

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Declaration of Competing Interest

None.

References

Abou-Raya, S., El Meguid, L.A., 2009. Road traffic accidents and the elderly. Geriatr. Gerontol. Int. 9 (3), 290–297. https://doi.org/10.1111/j.1447-0594.2009.00535.x.

American Association of State Highway and Transportation Officials (AASHTO), 2004. A Policy on Geometric Design of Highway and Streets. AASHTO, Washington, D.C.

Bailey, S.S., Jones, S.A., Stout, R.J., Bailey, J.H., Kass, S., Morgan, B.B., 1992. Issues of elderly pedestrians. Transp. Res. Rec. 1375, 68–72.

Blackburn, L., Zegeer, C., Brookshire, K., 2017. Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations. FHWA-SA-17-072. Federal Highway Administration, Washington, D.C.

Blackburn, L., Zegeer, C., Brookshire, K., 2018. Field Guide for Selecting Countermeasures at Uncontrolled Pedestrian Crossing. FHWA-SA-18-018. Federal Highway Administration, Washington, D.C.

Carmeli, E., Coleman, R., Omar, L.H., Brown-Cross, D., 2000. Do we allow elderly pedestrians sufficient time to cross the street in safety?. J. Aging Phys. Act. 8, 51–58. https://doi.org/10.1123/japa.8.1.51.

City of Los Angeles, 2018. Vision Zero: 2018 Action Plan and Progress Report. Los Angeles, CA: City of Los Angeles. .

City of Minneapolis, 2017. Evaluation of Bicycle Traffic Control Devices and Street Design Elements in Minneapolis. Minneapolis, MN: City of Minneapolis. http://www.minneapolismn.gov/www/groups/public/@publicworks/documents/images/wcmsp-195594.pdf retrieved on September 19, 2018. .

Dommes, A., Cavallo, V., Vienne, F., Aillerie, I., 2012. Age-related differences in street-crossing safety before and after training of older pedestrians. Accid. Anal. Prev. 44 (1), 42–47. https://doi.org/10.1016/j.aap.2010.12.012.

Davis, G., 2001. Relating severity of pedestrian injury to impact speed in vehicle-pedestrian crashes. Transp. Res. Rec. 1773, 108–113. https://doi.org/10.3141/1773-13.

Gorriea, C.A., Brown, J., Waite, P., 2008. Crash characteristics of older pedestrian fatalities: dementia pathology may be related to 'at risk' traffic situations. Accid. Anal. Prev. 40 (3), 912–919. https://doi.org/10.1016/j.aap.2007.10.006.

Kim, D., Kim, K., 2015. The influence of bicycle oriented facilities on bicycle crashes within crash concentrated areas. Traffic Inj. Prev. 16 (1), 70–75. https://doi.org/10.1080/15389588.2014.895924.

Kim, J.-K., Ulfarsson, G.F., Shankar, V., Kim, S., 2008. Age and pedestrian injury severity in motor-vehicle crashes: a heteroskedastic logit analysis. Accid. Anal. Prev. 40 (5), 1695–1702. https://doi.org/10.1016/j.aap.2008.06.005.

Mather, M., Jacobsen, L.A., Pollard, K.M., 2015. Population Bulletin; Aging in the United States. Population Reference Bureau., Washington, D.C.

National Highway Traffic Safety Administration (NHTSA), 2017. Traffic Safety Facts 2015. NHTSA, Washington, D.C.

Organization for Economic Co-operation and Development (OECD), 2001. Ageing and Transport: Mobility Needs and Safety Issues. OECD, Paris.

Oxley, J., Corben, B., Fildes, B., Charlton, J., 2007. Older pedestrians – meeting their safety and mobility needs. The Proceedings of 11th International Conference on Mobility and Transport for Elderly and Disabled Persons (TRANSED).

Oxley, J., Fildes, B., Ihsen, E., Charlton, J., Day, R., 1997. Differences in traffic judgements between young and old adult pedestrians. Accid. Anal. Prev. 29 (6), 839–847. https://doi.org/10.1016/S0001-4575(97)00053-5.

Shankar, V.N., Sittikariya, S., Shyu, M.-B., 2006. Some insights on roadway infrastructure design for safe elderly pedestrian travel. IATSS Res. 30 (1), 21–26. https://doi.org/10.1016/S0386-1112(14)60152-7.

Staplin, L., Lococo, K., Byington, S., Harkey, D., 2001. Highway Design Handbook for Older Drivers and Pedestrians. FHWA-RD-01-103. US Department of Transportation, Washington D.C.

Thomas, L., Sandt, L., Zegeer, C., Kumfer, W., Lang, K., Lan, B., Horowitz, Z., Butsick, A., Toole, J., Schneider, R.J., 2018. Systemic Pedestrian Safety Analysis. National Cooperative Highway Research Program (NCHRP) Research Report 893. Transportation Research Board, Washington, D. C.

Zegeer, C.K., Stutts, J.C., Huang, H., Zhou, M., Rodgman, E., 1993. Analysis of elderly pedestrian accidents and recommended countermeasures. Transp. Res. Rec. 1405, 56–63.