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Patterns of Traffic Accidents Among Elderly Pedestrians in Sweden

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Abstract

The objective of this study is to characterize the nature and space-time patterns of traffic accidents involving elderly pedestrians in Sweden, in order to suggest preventive measures. The analysis is based on elderly pedestrian accidents from 2010 to 2014 using an age adjusted standardized elderly accidents ratios (ASEAR), Geographical Information Systems (GIS) and spatial statistics techniques. Findings show that the geography of elderly traffic accidents is far from being homogenous across the country: although most accidents happen in urban municipalities, 30 per cent of municipalities classified as accessible rural exhibit relatively high-standardized accidents ratios. They happen often in daylight hours, on weekdays and in the coldest months of the year. Most of the cases are single accidents (e.g. self-inflicted fall); they happen in street segments/intersections and pedestrian/bicycle path, some affected by environment conditions such as icy or uneven surfaces. Findings of the study call for preventive actions that are sensitive to the nature of these accidents in different temporal and spatial contexts.

Keywords: Vulnerable Road Users (VRU), older pedestrians, fall, cluster analysis, GIS

1. Introduction

Every year over 40 elderly pedestrians are killed and thousands injured in traffic in Sweden. Older adults and pedestrians both represent especially Vulnerable Road Users (VRU) in traffic (Niebuhr, Junge, & Rosén, 2016; Vanlaar, Mainegra-Hing, Brown, McAteer, Crain, & McFaull, 2016). VRU are defined as “non-motorized road users, such as pedestrians and cyclists as well as motor-cyclists and persons with disabilities or reduced mobility and orientation” (EC, 2015). In the EU, pedestrians accounted for 20% of all traffic fatalities whilst the elderly have a disproportionate share of pedestrian fatalities in accidents, accounting for almost 36% (EC, 2011). There is some controversy as to whether the number of fatalities are decreasing (EC, 2011; Vanlaar et al., 2016). Regardless of trends, there are clear international and national differences in the distribution of accidents with vulnerable road users (WHO, 2013), yet, little is known about regional variations within countries. In the EU countries, for instance, about two-thirds of accidents happen in the urban areas as the majority of walks are made in urban environments. Previous research has also shown that pedestrians 65 or older are overrepresented in accidents during certain times of the day, the week and vary also seasonally (e.g. Oxley & Fildes, 1999; Zegeer, Stutts, Huang, Zhou, & Rodgman, 1993), yet not many studies have devoted time to look at places where accidents concentrate both in time and space.

This study contributes to this knowledge by characterizing the nature and space-time patterns of traffic accidents involving elderly pedestrians in Sweden. First, we examine the most common accidents involving elderly pedestrians by municipality type and assess when they take place by hours of day, weekly and seasonally. Later, we identify those municipalities in which elderly pedestrians run higher risk of accidents (hot spots of accidents) after calculating an age adjusted standardized elderly accidents ratios (ASEAR) and using Getis-Ord statistics. Finally, we characterize the most common types of environments where accidents happen using a sample of accidents from highly targeted municipalities in order to suggest preventive measures.

As walking and cycling are becoming popular forms of exercise and a way of being more environmentally friendly, the safety of vulnerable road users is an important issue worldwide (WHO, 2007; 2008; 2011). In Sweden, although there have been many studies associating elderly pedestrians and risk of accidents (Larsson, 2009; Niebuhr et al., 2016; Ståhl, Carlsson, Hovbrandt, & Iwarsson, 2008; Svensson, Towliat, & Ullberg, 2008; Wennberg, 2011), none has looked into potential regional differences of where these accidents happen.

2. Theoretical Background

2.1 Temporal Patterns

In the US, Zegeer et al. (1993) carried out a study in North Carolina over 11 years involving vehicle crashes and older pedestrians that showed older pedestrians were overrepresented in crashes during daylight hours, on weekdays, and in winter. They were slightly less likely than younger pedestrians to be struck by a motor vehicle; however, once struck, older pedestrians have a much higher likelihood of being killed, 20%, compared with 5 to 10% for younger age groups. In Israel, Prato, Gitelman, and Bekhor (2012) found also that pedestrian fatalities were mainly registered during day (57.5%), generally during the morning and the afternoon off-peak periods.

In the South Hemisphere, in Australia, a contrasting pattern (hours, on weekdays) was reported but specially between 4pm and 8pm. Seasonally, while many such deaths occurred in the evening during winter, autumn and spring, a relatively large number also occur during summer mornings and evenings (NRTAC, 1995). In the UK, Lovelace, Roberts, and Kellar (2016) indicated slightly different pattern of accidents for cycling (happen during the daylight, for both cyclists and non-cyclists) but they concentrate during the summer. According to EC (2011) figures for Poland, Hungary and Estonia showed that a large portion of accidents with pedestrians happen in darkness, most certainly because these countries have relatively long winters, with short daylight hours.

2.2 Spatial Patterns

There are a number of aspects of the road environment relevant to pedestrian casualty crashes. The characteristics of the road and surroundings, location of the road section, type of traffic control and its compliance level, traffic and pedestrian volumes, any engineering innovations which alter usual functions, or other visibility are bound to affect road safety. Several road situations have also been identified as potential hazards for older pedestrians due to the difficulty they present to older adults. These include intersections, reversing vehicles, two-way traffic and tram stops (Oxley & Fildes, 1999).

Accidents with older pedestrians are overrepresented in street or road intersection (particularly involving turning vehicles) and in crashes involving wide street crossings (NRTAC, 1995). “The layouts of the pedestrian crossing, the presence of traffic lights and the applicable priority rules have a significant influence on the safety”. According to the EC (2011, p.26) a large portion of accidents in Europe, “between 10% and 20%, take place on pedestrian crossings”.

Although the analysis was not directed to crashes against pedestrians, the study by Rifaat, Tay, and de Barros (2011) showed that there is an effect of different street patterns on crash severity. They found that compared to other street patterns, loops and lollipops design increases the probability of an injury but reduces the probability of fatality.

One of the few studies that looked at regional patterns of elderly pedestrian was done by Prato et al. (2012). Using a database of pedestrian fatal accidents occurred during a four-year period, they found the existence of five pedestrian accident types: elderly pedestrians crossing on crosswalks mostly far from intersections in metropolitan areas; pedestrians crossing suddenly or from hidden places and colliding with two-wheel vehicles on urban road sections; male pedestrians crossing at night and being hit by four-wheel vehicles on rural road sections; young male pedestrians crossing at night wide road sections in both urban and rural areas and children and teenagers crossing road sections in small rural communities. Although these authors are able to identify distinct patterns of pedestrian accidents, they failed in making reference to where these accidents happen geographically (more than defining whether they were urban or rural) and to their spatial context of these accidents. They found that most pedestrian fatalities occur in urban areas (72.1%), in road sections (70.6%) and in the center of the country where the two major metropolitan areas are located (56.7%).

3. The Study Area

There are several reasons one should care about accidents among elderly pedestrians in Sweden. Firstly, the elderly compose only 10 percent of the exposure (Gustafsson & Thulin, 2003) but yet accidents are highly lethal among them (a third of the pedestrians killed were 75 years and older) (Larsson, 2009) costing more than 11 billion a year (Torstensson, Forslund, & Tegnell, 2011). The vulnerability of elderly in accidents in comparisons with other age groups has also been confirmed elsewhere, see Niebuhr et al. (2016).

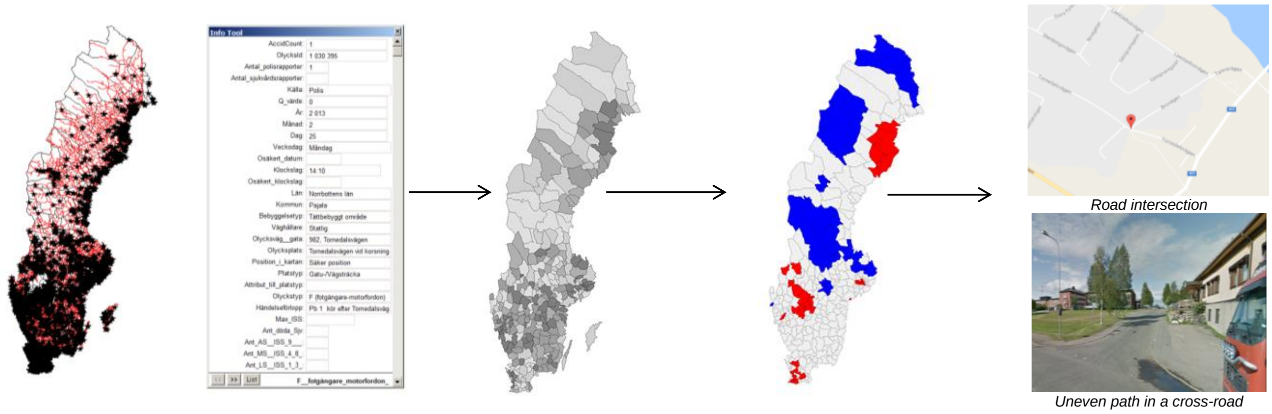
Secondly, the geographical distribution of the elderly population in Sweden is uneven across space. The proportion of the population aged 65 or older is significantly higher in rural municipalities than in other groups of municipalities (Statistics Sweden, 2010), as they do not often migrate to larger cities. In the last decade, the rate of growth of the older population has exceeded the growth rate of the country’s total population. While the total Swedish population increased by 5.7 %, the elderly population increased by 13.4 %. The number of older women has been greater than older men in all Swedish counties. The total population in Sweden was estimated in 2018 as 10,1 million people (Statistics Sweden, 2018). Sweden has relatively a low population density of 21 inhabitants per square kilometer (the corresponding figure for Denmark is 125) with the highest concentration in the southern half of the country. The older population is also mostly concentrated in the centre-South of the country, namely Stockholm, Västra Götland, Skåne, and Östergötland (Bamzar & Ceccato, 2015), where its principal cities are located, the capital Stockholm and southwestern Gothenburg and Malmö. Of Sweden's nearly 10 million inhabitants, about two million live in rural areas. Of these, 200,000 live in remote rural regions. But this is not only a challenge in Sweden, the world's population is aging, especially in countries of Global North. In the Nordic countries, for instance, the highest proportion of elderly people aged 65 years and over is found in Sweden and Finland. In Sweden as many as 20% of the population is over 65 (more than 1,6 million, SCB, 2016), by 2020, it will be 25% of the population (Schyllander & Rosenberg, 2010) whilst the number of people above 100 years old has triplicated since the 1990s, 1896 people in 2015 (SCB, 2016).

Thirdly, risk of accidents among the elderly pedestrians varies across the country. Sweden has long cold winters (-15 degrees) and several dark hours a day but in southern Sweden, climate is usually milder (with an average annual temperature of 0 degrees) than in the north. This may imply that counties in the North are associated with the long lasting snow cover in winter in comparison to the southern counties. The maximum yearly temperature also differs—from 6.7 C in north and 12.6 C in the South. These temperature differences affect the elderly lifestyles, consequently, their mobility, and the risk of accidents. Finally, risk of injury among the elderly varies between men and women and by nature (Bamzar & Ceccato, 2015, 2016). The oldest group accounts for many of injury cases where the proportion of women is over 70 per cent (Larsson, 2009). Older individuals avoid going out if the outdoor environment and infrastructure 'do not help', for example, lack of seating, poor snow removal or lighting, toilets, crosswalks or protected bus stops, uneven road surfaces, perceived traffic, specially 'fast traffic' (Ståhl et al., 2008; Wennberg, 2011).

4. Data and Methods

The set of data used in this analysis is described in Appendix 1. The study is based on data from STRADA (Swedish Traffic Accident Data Acquisition) database on accidents among elderly pedestrians by type from 2010 to 2014. The STRADA information system is a coordinated national registration of traffic accidents and traffic injuries run by the police and the health care authorities and was obtained from The Swedish Transport Agency. This information system concerns the whole road transport system and since 2003 the police report data cover the entire country, and currently half of all hospitals with emergency units. Organizations such as the Police, the National Federation of County Councils, the National Board of Health and Welfare, the Swedish Association of Local Authorities, the Swedish Institute for Transport and Communications Analysis (SIKA), and Statistics Sweden (SCB), co-operate with the Swedish Road Administration (SRA).

Events of accidents (x,y coordinates of each event) as well as municipalities are used as unit of analysis in this study. Data for this study was obtained from different sources. Google maps and internet engine was used to locate and inspect selected cases of accidents in municipalities with high concentrations of cases. Statistics Sweden was used to collect the demographics as well as the boundaries of the municipalities. Swedish Transport Administration was the source of GIS data on street and road network as well as built up areas. "Municipality" has been chosen as "the second" unit of analysis in this study because it is the smallest administrative unit in Sweden, which allows comparisons of the official statistics at national level. Municipalities have been grouped in three types: Remote Rural (RR), Accessible Rural (AR) and Urban Areas (UA) according to the definition suggested by the former National Rural Development Agency. Thus, Remote Rural (RR) areas are more than 45 min by car from the nearest urban neighborhood with more than 3000 inhabitants, whilst Accessible Rural (AR) areas are 5-45 min by car from urban locations with more than 3000 inhabitants. Municipalities with more than 3000 inhabitants and reachable in 5 min by car are regarded as Urban Areas (UA). Note that both urban and rural municipalities have an urban core surrounded by a sparser housing pattern. The difference between urban and rural municipalities is the size of the urban core and distance between them. The municipalities have an average population size of 31 thousand inhabitants (from a minimum of 2.6 up to 766 thousand inhabitants). For details, see Ceccato and Dolmen (2011).



(1) Mapping accidents involving elderly pedestrians by co-ordinates
(2) Calculating Age Adjusted Standardized Accidents Ratios
(3) Detecting hot spot & cold spots
(4) Characterizing the location of accidents in hot & cold spot areas

Figure 1. Methods characterizing the nature and space-time patterns of traffic accidents involving elderly pedestrians.

(1) **Mapping accidents involving elderly pedestrians by coordinates** - The database on accidents among elderly pedestrians by type from 2010 to 2014 was collapsed into one dataset to allow a more robust analysis at municipality level. The x,y coordinates of these accidents were mapped against built up areas, street/road network and boundaries of the municipalities using GIS as illustrated in Figure 1. Demographic data was also linked to the Swedish municipalities, namely total elderly population for 2014. Frequency analysis of the characteristics of the accidents offers only a blurred picture of pedestrian fatal accidents (Prato et al., 2012), therefore we calculate Age Adjusted Standardized Elderly Accident Ratios (ASEAR).

(2) **Calculating Age Adjusted Standardized Elderly Accident Ratios** (ASEAR) **-** In order to have a measure of relative risk of the accidents of elderly pedestrians in Sweden at municipal level, an Age Standardized Elderly Accidents Rates (ASEAR) were calculated based on the population of interest (65 years old and above). Traditionally, this type of standardization is used to represent data for a study area (set of municipalities that differ in size and where it is necessary to allow for differences in population characteristics between areas. In the case of accidents data, this adjustment process improves as a measure of risk variability across the map (Haining, 1990, 2003). The ASEAR for municipality *i* is given by dividing the observed number of accidents among elderly pedestrians in Sweden (O(*i*) in each municipality by the expected number of accidents of a given type (E(*i*)), described as the following:

$$ASEAR(i) = [O(i)/E(i)] * 100 \quad (1)$$

The expected counts were calculated by creating an average rate for Sweden by dividing the total number of accidents of a given type by the total size of the population aged 65 years and older. For each municipality *i*, this average rate is multiplied by the size of the elderly population in municipality *i* to yield E(*i*) and then multiplied by 100. Values higher than 100 show higher risk in that unit taking account the distribution of the total accidents by elderly population in that municipality and in whole Sweden.

(3) **Detecting hot and cold spots of accidents –** To identify significantly high accident concentrations taking into account the whole distribution of accidents in Sweden, a local indicator of spatial association was calculated in GeoDa (Anselin, 2003). Getis-Ord statistics (Anselin, 1995; Getis & Ord, 1992) was applied to the ratios of accidents per municipality using total population aged 65 and older as the denominator. This cluster technique can be useful to detect local pockets of dependence that may not show up using global measures of spatial association (Getis & Ord, 1992; Karlström & Ceccato, 2002). The significance of the z-value of each local indicator can be computed under the assumption that attribute values are distributed at random across the area. The formula is the following:

$$G_i = \frac{\sum_j w_{ij}(d)x_j}{\sum_j x_j} \quad (2)$$

where the *wij(d)* are the elements of the contiguity matrix for distance *d*, in this case, a binary spatial matrix. In a simple 0/1 matrix, "1" indicates that the Swedish municipalities have a common border, "0" otherwise. This procedure accounted for the spatial configuration of the study area (all the Swedish municipalities, excluding the islands of Gotland and Öland); the weight matrix that was row standardized was used. When the model provides a measure of spatial clustering that includes the observation ($j = i$) under consideration, in other words, when the core area is included, the model is called *Gi**, as it was used in this analysis. Maps were created showing the statistically significant positive (hot) and negative (cold) Gi* clusters, using randomization (99 permutations, with values smaller than 0.010).

(4) **Characterizing the location of accidents in hot and cold spot areas –** Using the results from the cluster analysis as a reference, an exploratory inspection of the location of a selection of these accidents (visual audit) was performed using internet search engine and Google maps. The coordinates and addresses attached to each event of these selected cases were identified in Google maps. The inspection included between 25 and 30 locations by accident types. The inspection searched for environmental clues, such as type of pavement, weather conditions, land use, visibility, illumination, count of people as well as indications of poor maintenance of the location and overall area. This template was used to inspect a selection of all types of accidents involving elderly pedestrians, focusing on municipalities that have been classified by Gi-statistics as hot spots of elderly accidents (Figure 1).

5. Results

Overall, between 2010 and 2014 there were 218453 accidents in Sweden, of which a third (73184) of these accidents involved pedestrians, and 36 per cent had victims who were 65 years and older. However, it is difficult to ascertain the most dominant cause of accidents among elderly pedestrians. One of the reasons is that among those who are 65 and older, 90 percent of accidents happened as a single pedestrian accident, namely they are "self-inflicted falls" (Table 1). This means the person may have tripped on uneven pavement, or slipped in an icy patch and fell, or lost balance and fell, felt dizzy and fell and/or was under substance, medicine, drugs or alcohol. Some of these events are easier to prevent, such as snow ploughing or eliminate uneven pavement, while others are a challenge, as they be related to the individual's physical, social and medical conditions (Bamzar & Ceccato, 2015; 2016). Table 1 shows that accidents happened when a motor vehicle collided with the elderly (8,4 percent) or was caused in combination with a bicycle, another person or a small motorcycle (1,4 per cent of cases).

Table 1. Total injuries happening outdoors, injuries with pedestrians, and with victims 65 years and older, Sweden 2010-2014.

	Injuries	Injuries with victims 65 years and older	% of injuries with pedestrians 65 years and older
Total	218453	45492	
Total of accidents with pedestrians	73184	26268	
Pedestrian-motor vehicle (F)	8007	2204	8,4%
Pedestrians-single* (G0)	63428	23662	90,1%
Pedestrian-cyclist (G3)	1276	316	1,2%
Moped-pedestrian (G6)	308	29	0,1%
Pedestrian-pedestrian (G8)	165	57	0,1%

Data source: The Swedish Transport Agency, STRADA database, 2010-2014. * Self-inflicted cases.

The average number of cases between 2010 and 2014 was 5253 with a minimum in 2010, with 4651 cases and a maximum of 6064 in 2013; an increase of 30% between 2010 and 2013 but 10% between 2010 and 2014, with 5092 cases.

5.1 The Temporal Nature of Accidents Among Elderly Pedestrians

Around two-thirds of the accidents involving elderly pedestrians happen in the daylight (10:00 and 17:00) (Figure 2(a)). For fatal cases (213 cases), two peak hours are found, one around midday and late afternoon. The accidents mostly happen when the elderly are walking, shopping, going out with a pet, running daily errands. These activities are part of the common daily routines of older individuals and are necessary for independent living. These accidents therefore happen more often during weekdays than weekends (Figure 2(b)) and in the coldest months of the year (Figure 2(c)), especially from November to February, when the maintenance of the urban infra-structure (e.g., snow ploughing, illumination) may have a fundamental role on the occurrence of the accident, as in many cases exemplified as below:

> *I slipped due to uneven road surfaces, un-ploughed sidewalk, with no sand or stone (accident with medium injuries, North Sweden).*
>
> *On the way to the mailbox, I slipped on a patch of ice (accident with minor injuries, Central Sweden).*

Similar patterns were found in the international literature for the US and some European countries (EC, 2011; Zegeer et al., 1993) for incidence of accidents by hours of the day, days of the week and seasonally. Less than half of *fatal accidents* happen when the individual fall by unknown or medical reasons (in only in a minority of cases due to street conditions, such as icy or uneven pavement), making more difficult to prevent. The majority of cases take place in collision with a vehicle, especially when car, bus or truck reversed paying no attention to road users. Individual’s difficulty in hearing or seeing combined with darker daylight conditions in the winter could contribute to higher risk of being hit by a motor vehicle as in the case described below:

> *The driver has reversed his vehicle while a pedestrian walked out of the gate with the walker. The driver has not observed the pedestrian and hit him and he ended up under the car* (fatal accident in North Sweden, 2011).

Figure 2. Hourly, daily and seasonal variations of accidents among elderly pedestrians.

Data source: Source: The Swedish Transport Agency, STRADA database, 2010-2014.

5.2 Spatial Patterns of Accidents Among Elderly Pedestrians

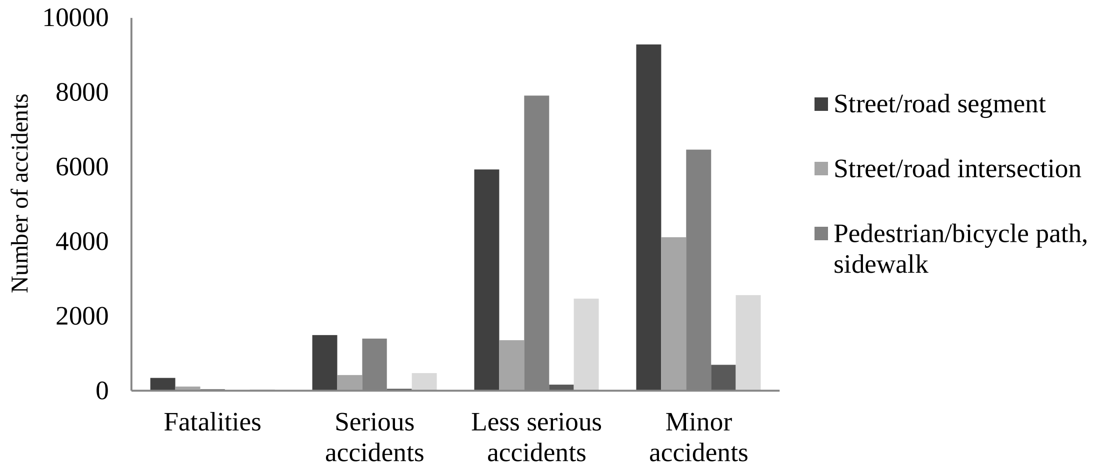
The following discussion of the results has two levels of analysis. The first level of results shows the distribution of the accidents by type and place in the cities. Some detailed environmental features of accident’s locations are also discussed based on the inspection of about 25-30 locations by accident types, sometimes covering several neighboring ‘hot spot’ municipalities. The second level of results discusses the regional distribution of accidents at municipal level and by type of municipalities (remote rural, accessible rural and urban).

- *Accidents and their settings*

Most of accidents involving elderly victims are single accidents (e.g. fall), self-inflicted falls that happens often in street or road segments, then followed by pedestrian/bicycle path, sidewalk and then street or road intersection (Figures 3(a) and 5(a)). These results fit previous studies of elderly fall in Sweden using health data as basis. They showed that most falls indoors and in the nearly environment were by slipping, tripping, and stumbling (57 % of the elderly falls) (Bamzar & Ceccato, 2015; 2016). Half of accidents are characterized by minor injuries, especially those happening in roundabout/parking areas. Among those accidents that are lethal, 63 per cent happen in street or road segments and 20 percent in street or road intersections.

Note that street/road segments are particular important components of accidents that involve elderly pedestrians and vehicles as well as *mopeds* (small motorcycles). Accidents with bicycles and small motorcycles often happen as it could be expected in bicycle and pedestrian paths/lanes (Figure 3(b)). Note that accidents that happen in collision with other person often happens when the person is on the move, often in the pavement or pedestrian/bicycle path, where often wheel chairs, skateboards, walkers, bicycles, kids buggy share space with pedestrians, as exemplified below:

> *I went on the pavement and a buggy drove on my leg and I fell into the street* (accident with minor injuries, Central Sweden).
>
> *I was pushed down from behind by a wheelchair* (accident with minor injuries, North Sweden).
>
> *I fell at Gustav Adolfs torg hit by youngsters on skateboards* (accident with minor injuries, South Sweden).
>
> *A small child ran into me… I fell and hit my head* (accident with minor injuries, Central Sweden).



(a)

	Pavement	Bus stop/train	Road interse	Road segment	Pedestrian_bicycle path	Other
Pedestrian_vehicle	2%	1%	21%	51%	2%	24%
Pedestrian_single	41%	3%	3%	25%	14%	13%
Pedestrian_bicycle	14%	0%	9%	24%	45%	7%
Pedestrain_moped	10%	0%	0%	41%	41%	7%
Pedestrian_pedestrian	33%	12%	7%	18%	18%	12%

(b)

Figure 3 (a) Number of accidents in transit by severity and location type, with victims 65 years and older, Sweden 2010-2014. (b) Percentage of accidents by type and location, with pedestrians 65 years and older, Sweden 2010-2014. Data source: Source: The Swedish Transport Agency, STRADA database, 2010-2014.

The inspection of locations by accident types shows recurrent keywords such as “uneven pavement”, “icy and slippery streets”. As Figure 4 illustrates these keywords are important for preventing elderly accidents because they provide clues of the types of environments that need more attention by the municipalities. Simple inspections as shown in Figure 4 should be used to prevent these accidents. Figure 4 suggests that pedestrian accidents mainly occur on several arterial and collector streets in the most central parts of the urban areas, where most of inner city activities take place, with a high concentration of population during the day.

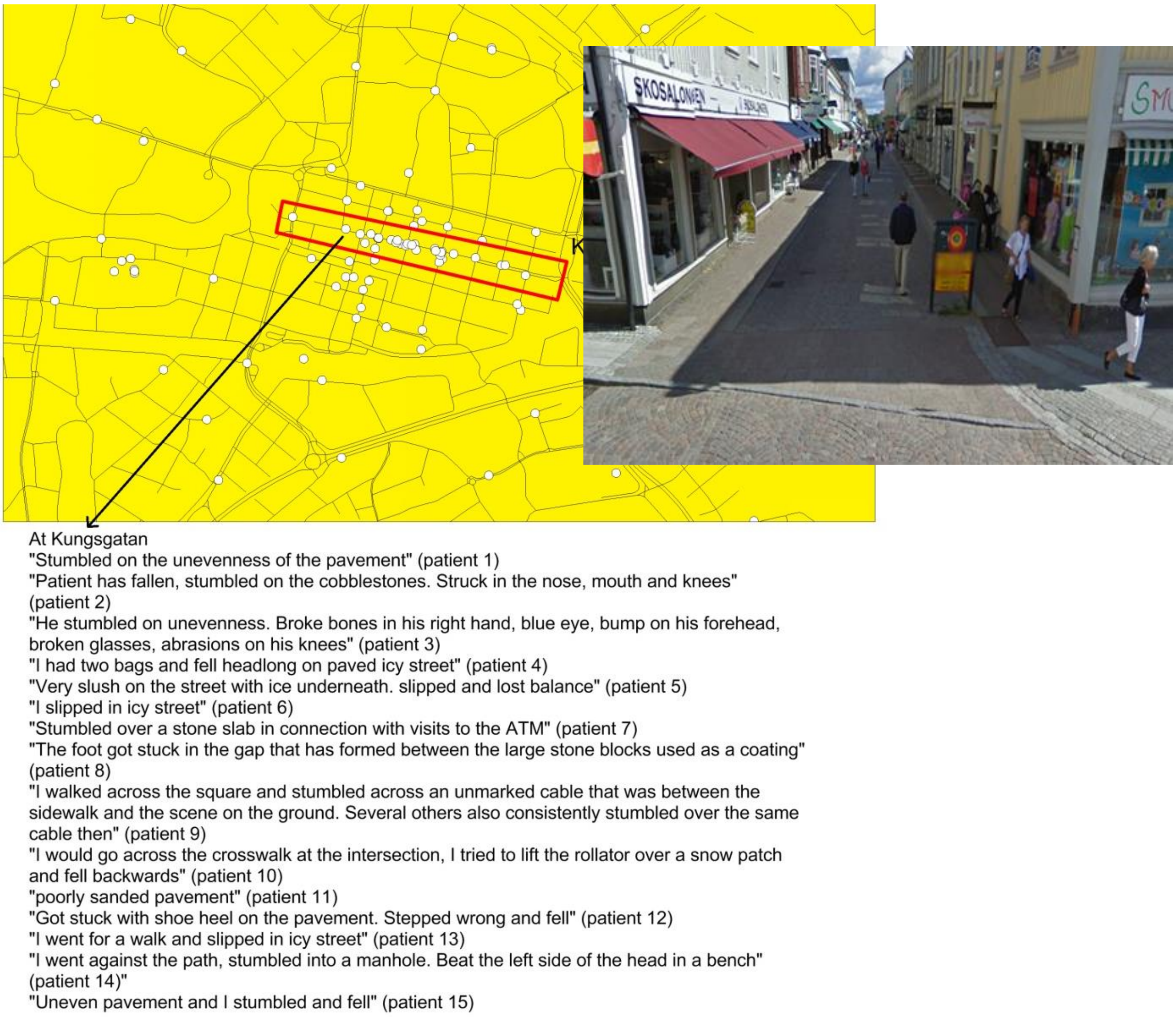


Figure 4. Uneven stones and icy street: Typical causes of accidents among elderly pedestrians in accessible rural Swedish municipalities.

These streets are typical in many urban areas in Sweden, regardless municipality size or location. Some municipalities in the north show cases in which illumination (in other words, darkness) might also be a problem while in the south recurrent links to “management”, “poor education in traffic” are also pointed out as problematic and the cause of accidents.

Outside urban areas, there are cases of accidents involving elderly pedestrians along the roads. Vehicles (motorcycles, mopeds, snowmobile) are often overrepresented in this group of accidents that happen when individuals are crossing the road, walking along the road (with a pet), a vehicle hits a pedestrian from behind, or when the vehicle reverse and hit the person.

Distribution of elderly accidents by municipality

Despite the fact that two thirds of accidents involving elderly take place in municipalities classified as “urban” (Figure 5(b)), the distribution of accidents is far from being homogeneous across the country. As expected, more than half of the cases happen in the center-south of the country, namely where Stockholm, Gothenburg and Malmö are located. These results are in accordance with previous findings in Israel. Prato et al. (2012) also identified that two-thirds of pedestrian fatalities happened in urban areas, in road sections and in the center of the country where the two major metropolitan areas are located (in 56.7 per cent of cases).

In Sweden, 25 per cent of accidents take place in municipalities classified as “rural” (Figure 5(b)). As many as 30 percent of accessible rural municipalities exhibit relatively high risk of accidents for older pedestrians (Appendix 2). The percentage for urban municipalities is 26 per cent and 23 per cent among remote rural municipalities. Note that the Age Adjusted Standardized Accidents Ratios (ASEAR>100 per municipality type) presented in Appendix 2 are calculated splitting cases and population by the three types of municipalities while ASEAR shown in Figure 6 assume all accident cases by elderly population to all Swedish municipalities.

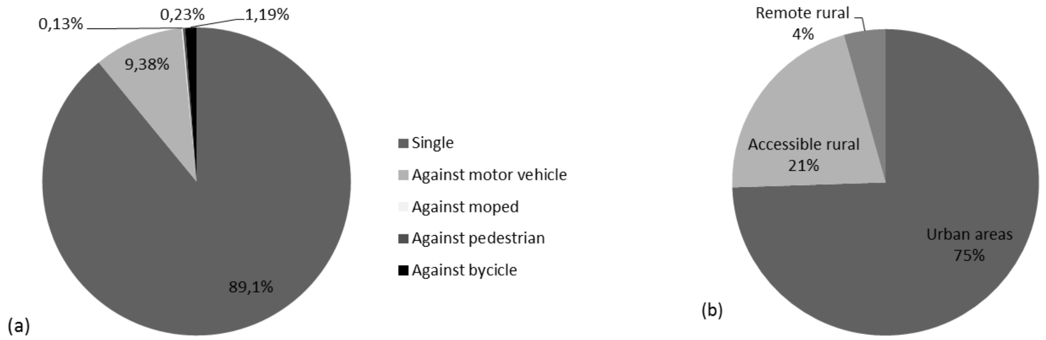


Figure 5. (a) Elderly pedestrian accidents per type (%), Sweden 2010-2014 and b) Elderly pedestrian accidents as proportions by municipality type (%). Data source: Source: The Swedish Transport Agency, STRADA database, 2010-2014.

Figure 6 shows in dark grey municipalities that exhibit observed number of accidents greater than the expected considering the distribution of the total accidents by elderly population in that municipality and in whole Sweden. Despite clear concentration patterns, any attempt to explain these geographical variations goes beyond the scope of this article. Yet, a discussion of the characteristics of these hot and cold spots of accidents can be made below.

Municipalities in Northern Sweden, especially along eastern coast, tend to have relatively high ratios of accidents and a number of stable hot spots for different types of accidents involving elderly pedestrians, namely for single accidents and those in connection with motor vehicle (Figures 6 and 7). These findings corroborate previous results looking at elderly fall using hospital admission data (Bamzar & Ceccato 2015).

Long cold winters in the Northern municipalities associated with long dark hours, many snowy months, increase the risk of accidents among the elderly than is the case in Southern municipalities. Previous research has suggested that limited access to sunlight, especially in winter, may result in poor visual acuity which is the potential risk factors for accidents (Bergstralh, Sinaki, Offord, Wahner, & Melton, 1990). Another aspect that can be associated with these patterns of accidents is the poor accessibility to basic daily services. Bamzar & Ceccato (2015) suggest that the high risk of accidents, especially falls, can also be associated with inadequate access to basic services such as grocery stores as well as the number of paved streets. These authors indicate that whereas in Sweden there is an average of 24 per cent unpaved streets, in some of the Northern rural counties, the percentage of unpaved streets can reach 58 per cent, which certainly put more individuals at risk.

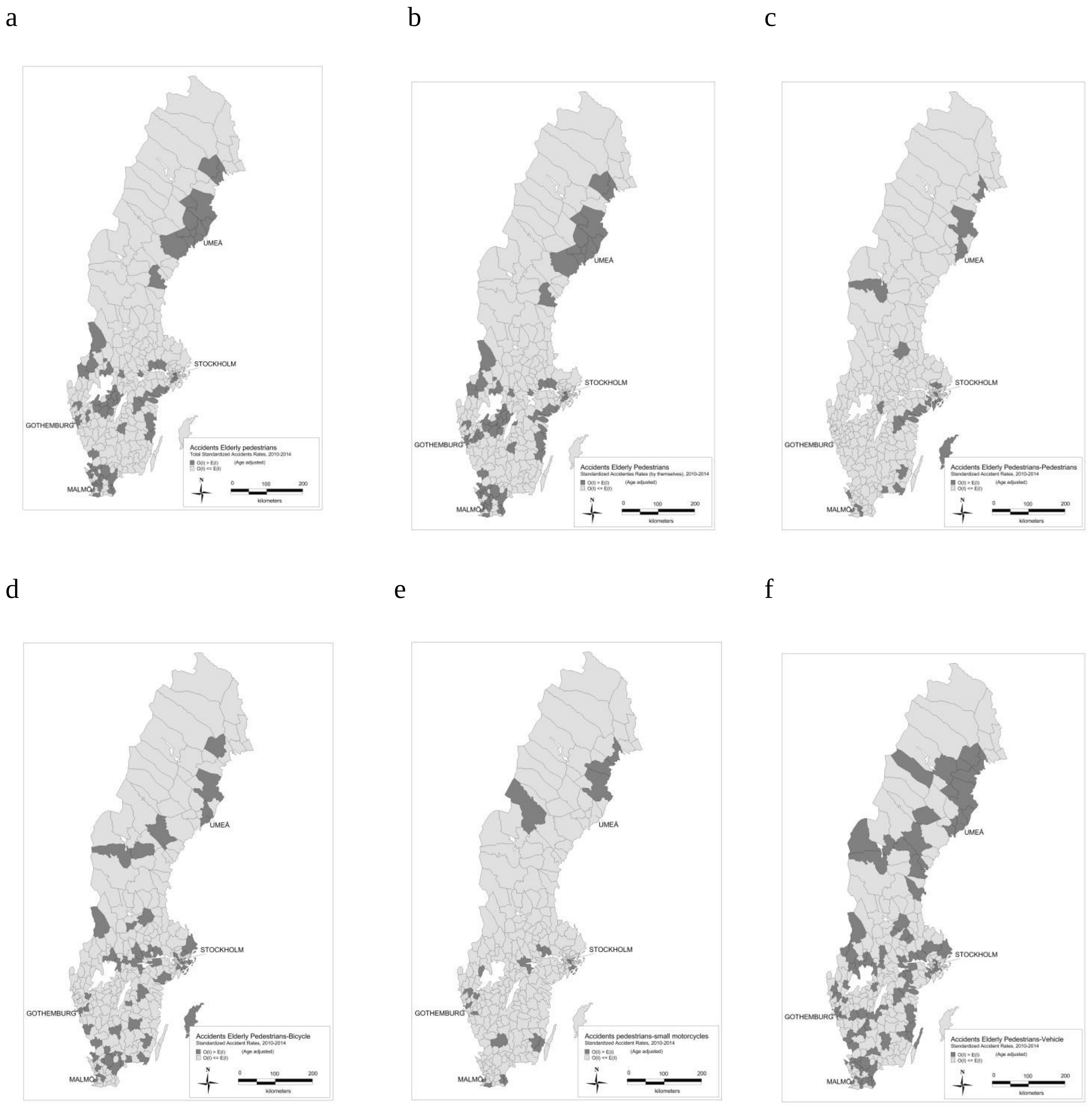


Figure 6. Age Adjusted Standardized Accidents Ratios, Total population (aged 65+) as basis. (a) Total pedestrians accidents 2010-2014; (b) Pedestrian by him/herself; (c) Pedestrian-pedestrian; (d) Pedestrian-bicycle, (e) Pedestrian-small motorcycle (moped), (f) Pedestrian-vehicle. Note: *Maps (c) and (e) are based on few observations and should therefore be analyzed with caution.*

Long cold winters alone do not help in explaining hot spots of accident among elderly pedestrians in other parts of the country. Note for instance that many ‘cold spots’ of accidents among elderly pedestrians are also found in many parts of Northern Sweden, but specially in western parts of the country (Figure 7), in large northern municipalities (mostly certainly because of the lack of cases and/or low population counts in those municipalities). They are often municipalities classified as remote rural.

Patterns of daily routine activity by older adults in central and southern parts of the country can be associated with municipalities with higher risk of accidents (Figure 7), including pedestrians and other VRU in traffic within the cities and commuting along the roads between municipalities. Moreover, variations of risk of accidents should also reflect the municipality’s capacity to provide maintenance of urban and rural infrastructure, such as quality of pavement of street and roads, illumination, maintenance of bus stops along street and roads.

Figure 7. Clusters of accidents – Hot and cold spots - Elderly pedestrians (Getis-Ord statistics) (a) Total pedestrians accidents 2010-2014; (b) Pedestrian by him/herself; (c) Pedestrian-pedestrian; (d) Pedestrian-bicycle, (e) Pedestrian-small motorcycle (moped), (f) Pedestrian-vehicle. *Note: Maps (c) and (e) are based on few observations and should therefore be analyzed with caution.*

Less interesting but equally important, is the fact that the geography of accidents reflects individual's willingness and need to properly report these events as they happen (when being rescued by the emergency services, such as the ambulance, police or health personal). Some counties tend to be better in reporting these incidents and their municipalities tend therefore to have a relatively and consistently high number of records (e.g, Västerbotten county). Consequently, these counties with better practices of reporting will turn into hot spots of accidents while those that fail in reporting accidents might classified as a 'cold spot' of accidents.

6. Conclusions and Looking Ahead

One of the important messages of this study is that risks of accidents to elderly pedestrians as VRU are context-specific and time-dependent. Older pedestrians are overrepresented in accidents during daylight hours, on weekdays, and in winter – confirming some of previous results found elsewhere. The analysis also showed that the geography of elderly accidents varies across the country (concentrated in urban municipalities), by types of accident and types of locations. Most of accidents involving elderly victims are a single accident (e.g. self-inflicted fall) that happens often in street or road segments, followed by pedestrian/bicycle path and lanes. Appendix 2 shows a list of municipalities that should be given priority in terms of resources devoted to combat accidents among elderly pedestrians.

The resulting insights have the potential to influence policy. Geographical localized analysis - as exemplified in this study can provide a fast and inexpensive insight for local authorities devoted to improving safety for VRUs. Interventions to improve safety resulting from this research should include therefore tailored changes in the environment where most of accidents happen, especially in those municipalities that are heavily affected by the problem (see the list of municipalities in Appendix 2). Further inspection in these hot spots of accidents involving elderly pedestrians is needed, so preventive actions can be more targeted to local needs. There is a need to focus on changes in particular streets and other settings where elderly constantly have accidents, such as the case illustrated in Figure 4. Streets and squares with uneven cobblestones can be particularly dangerous for elderly pedestrians and should be carefully maintained or in extreme cases replaced by other street materials. Note that uneven surfaces do not normally put an individual at risk for fall but in certain contexts and to older adults with limited movements, they can be risky. Therefore, there is a need to identify barriers to movement for the elderly, including inappropriate sidewalks and the poor quality of street paving, especially in winter. Furthermore, having easy access to basic services can be regarded as preventive against accidents. Installing seats in public spaces on the way from elderly homes to these basic services, but also toilets and street holding support in particular uneven places (known accident hot spots) can also be considered as preventive measures in municipalities with high concentrations of elderly accidents. Cooperation between local actors devoted to maintenance of urban infrastructure and traffic is therefore fundamental.

Since many cases of collision with vehicles in Sweden happens when people are reversing their vehicle, measures that help the driver to notice pedestrians and possibly intervene in the driving route to avoid collisions would be desirable. Blind Spot Detection Systems help to perceive pedestrians that are outside the field of view of the driver. Solutions can include Intelligent Pedestrian Traffic Signal control that extends the "green time" to those pedestrians more than average time to cross the road. Moreover, there are concerns about the risk of accidents with the advent and dissemination of electrical vehicles as they produce little noise, which can be extra problematic to those with hearing problems or visual impairments since they constitute a relatively large share of elderly individuals.

Overall, it is fundamental to improve the visibility of pedestrians in darkness, especially in Northern Sweden where long winters with short days may put older people at risk in late afternoon hours. From pedestrian side, use of reflective clothing can prevent an accident but it should be complemented with effective illumination (and lighting from vehicles), especially in the outskirts and more rural areas. Moreover, icy patches in the streets are often pointed out as cause for falls and accidents among elderly pedestrians in Sweden. This demands constant maintenance (e.g., salt, sand) in the winter. Equally important is improving the layout and uniformity of pedestrian crossings. Uneven surfaces are often causes of self-inflicted accidents. With regards collision with motorcycles and vehicles, improvements include measures to reduce vehicle speed, to improve traffic signal compliance or in the less urbanized areas, to warn fast traffic for the presence of pedestrians (including for bicycles and motorcycles).

This study also leads to new research questions regarding accidents and VRUs. It is important to conduct a more systematic environmental audit of the built environment in which most accidents happen, that in this study was limited to a number of samples. Moreover, differences in maintenance of traffic and urban infrastructure as well as community health services in each municipality can certainly in future research help explaining variations in accidents among the elderly. Data permitting, future studies should include information about individual characteristics of those involved in these accidents, gender, health conditions, socio-economic condition. This can potentially provide a better understanding of individuals' vulnerability to accidents in old age in both urban and rural contexts. More importantly, is to find out whether and how municipalities differ in the amount of resources assigned to maintenance of basic urban infrastructure and traffic, and whether this difference implies in more/less accidents among VRUs, especially among the elderly that are overrepresented in the most rural municipalities in Sweden.

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References

Anselin, L. (1995). Local Indicators of Spatial Association—LISA. *Geographical Analysis*, *27*(2), 93-115.

Anselin, L. (2003). *GeoDa™ 0.9 User's Guide*. Spatial Analysis Laboratory. Department of Agricultural and Consumer Economics. University of Illinois, Urbana_ Champaign Urbana and Center for Spatially Integrated Social Science. https://s3.amazonaws.com/geoda/software/docs/geoda093.pdf.

Bamzar, R., & Ceccato, V. (2015). The nature and the geography of elderly injuries in Sweden. *GeoJournal*, *80*(2), 279–299.

Bamzar, R., & Ceccato, V. (2016). The regional ecology of elderly falls in Sweden. *GeoJournal*, *81*(1) 23–36.

Bergstralh, E. J., Sinaki, M., Offord, K. P., Wahner, H. W., & Melton, L. J. (1990). Effect on season on physical activityscore, back extensor muscle strength and lumbar bonemineral density. *Journal of Bone and Mineral Research*, *5*(4), 371–377.

Ceccato, V., & Dolmen, L. (2011). Crime in rural Sweden. *Applied Geography*, *31*(1), 119–135.

EC, European Commission (2015). *Intelligent transport systems - Mobility and transport.* http://ec.europa.eu/transport/themes/its/road/action_plan/its_and_vulnerable_road_users_en.htm

EC, European Commission (2011). *Safety and comfort of the Vulnerable Road User* - Final Report. https://ec.europa.eu/transport/sites/transport/files/themes/its/studies/doc/2011_05-safety-and-comfort-vulnerable-road-user.pdf.

Getis, A., & Ord, J. K. (1992). The Analysis of Spatial Association by Use of Distance Statistics. *Geographical Analysis*, 24(3), 189-206.

Gustafsson, S., & Thulin, H. (2003). *Gående och cyklister. Exponering och skaderisker i olika trafikantmiljöer för olika åldersgrupper*. VTI, Stockholm, 928. https://www.diva-portal.org/smash/get/diva2:673734/FULLTEXT01.pdf.

Haining, R. (1990). *Spatial data analysis in the social and environmental sciences*. Cambridge: Campridge University Press.

Haining, R. (2003). *Spatial data analysis: Theory and practices*. Cambridge: cambridge University Press.

Karlström, A., & Ceccato, V. (2002). A new information theoretical measure of global and local spatial assocation. *The Review of Regional Research* (Jahrbuch für Regionalwissenschaf), *22*, 13-40.

Larsson, J. (2009). Fotgängares trafiksäkerhetsproblem: skadeutfall enligt po-lisrapportering och sjukvård. VTI, 627. https://www.transportstyrelsen.se/contentassets/0e7bc1082feb4738819200577c82a258/fotgangares-risker_vti-r671.pdf .

Lovelace, R., Roberts, H., & Kellar, I. (2016). Who, where, when: the demographic and geographic distribution of bicycle crashes in West Yorkshire. *Transportation Research Part F: Traffic Psychology and Behaviour*, *41*, Part B, 277-293.

Niebuhr, T., Junge, M., & Rosén, E. (2016). Pedestrian injury risk and the effect of age. *Accident Analysis & Prevention*, *86*, 121-128.

NRTAC, National Road Trauma Advisory Council (1995). Pedestrian Safety Report. National Road Trauma Advisory Council, AGPS, Canberra, February.

Oxley, J., & Fildes, B. (1999). *Safety of Older Pedestrians: Strategy for Future Research and Action Initiatives*. https://www.monash.edu/muarc/our-publications/muarc157.

Prato, C. G., Gitelman, V., & Bekhor, S. (2012). Mapping patterns of pedestrian fatal accidents in Israel. *Accident Analysis & Prevention*, *44*(1), 56-62.

Rifaat, S. M., Tay, R., & de Barros, A. (2011). Effect of street pattern on the severity of crashes involving vulnerable road users. *Accident Analysis & Prevention*, *43*(1), 276-283.

Schyllander, J., & Rosenberg, T. (2010). Skador bland äldre i Sverige. Retrieved from Karlstad https://www.msb.se/RibData/Filer/pdf/25570.pdf.

Statistics Sweden (2010) *Population statisics*. http://www.scb.se/

Statistics Sweden (2015) *Statistikdatabasen*. http://www.scb.se/

Statistics Sweden (2016) *The future population of Sweden 2016–2060*. http://www.scb.se/

Statistics Sweden (2018) *Sweden population.* http://www.scb.se/

Ståhl, A., Carlsson, G., Hovbrandt, P., & Iwarsson, S. (2008). "Let's go for a walk!": identification and prioritisation of accessibility and safety measures involving elderly people in a residential area. *European Journal of Ageing*, *5*(3), 265-273.

Svensson, H., Towliat, A., & Ullberg, M. (2008). *Tillgängligare, säkrare och tryggare gångmiljö för äldre personer - en före- och efterstudie av förändringar i gångmiljön i en del av Malmö.* Publikation 2008:1. Malmö, Sverige: Vägverket Konsult.

Torstensson, G., Forslund, M., & Tegnell, A. (2011). *Förslag till nationell handlingsplan för säkerhetsfrämjande arbete för äldre personer*. Stockholm, Socialstyrelsen. http://www.kunskapsguiden.se.

Vanlaar, W., Mainegra Hing, M., Brown, S., McAteer, H., Crain, J., & McFaull, S. (2016). Fatal and serious injuries related to vulnerable road users in Canada. *Journal of Safety Research*, *58*, 67-77.

Wennberg, H. (2011). *Trygga och säkra gångmiljöer för äldre fotgängare – Jämförelse av upplevelser och objektiv säkerhetssituation.* Trivector, Stockholm, *27*, https://www.trafikverket.se/contentassets/53419444de334f27afe602c9f1555475/2011_27_skyltfonden_trygga_och_sakra_gangmiljoer_for_aldre.pdf

WHO, World Health Organization. (2007). Global age-friendly cities: A guide. https://www.who.int/ageing/en

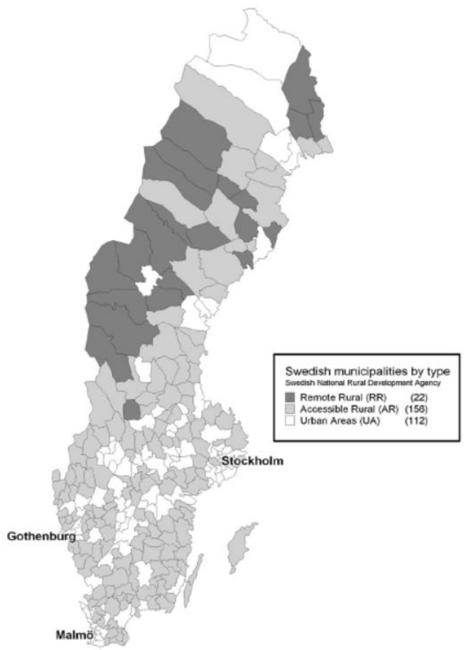
WHO, World Health Organization (2008). WHO global report on falls prevention in older age. https://extranet.who.int/agefriendlyworld/wp-content/uploads/2014/06/WHo-Global-report-on-falls-prevention-in-older-age.pdf.

WHO, World Health Organization (2011). World report in disability. http://whqlibdoc.who.int/publications

WHO, World Health Organization (2013). Global status report on road safety 2013: Supporting a decade of action. http://www.who.int/violence_injury_prevention/road_safety_status/2013/report/Paho_Roadsafetymanual_english_051515.pdf?ua=1.

Zegeer, C., Stutts, J., Huang, H., Zhou, M., & Rodgman, E. (1993). Analysis of elderly pedestrian accidents and recommended countermeasures. *Transportation Research Record*, (1405), 56-63.

Appendix 1 – The database of the study

Data type	Description	Source
Accidents among elderly 65+	Total accidents with pedestrians, Pedestrian-motor vehicle (F), Pedestrians-single (G0), Pedestrian-cyclist (G3), Moped-pedestrian (G6), Pedestrian-pedestrian (G8). Data on accidents include e.g., time, day, month, weekday, municipality, x,y coordinates, type of environment, road manager position in map, location type, chronology of events, degree of severity, suspicion of alcohol, road conditions, weather, street lights, police area.	The Swedish Transport Agency, STRADA database, 2010-2014, The Swedish Transport Agency (Transportstyrelsen)
Demographic data	Population age 65 and older by municipality	Statistics Sweden 2015
Geographical Data & pictures	a) GIS files of boundaries of the municipalities and codes of Swedish municipalities by type: Remote rural, Accessible Rural and Urban municipalities. b) Pictures of locations of accidents using internet search c) GIS files of built up areas, streets, roads, pavement areas, paths over Sweden 	Statistics Sweden 2014; Categories based on the definitions from the National Rural Development Agency (Glesbygdsverket) Google maps, 2016 Swedish Transport Administration (Trafikverket)

Appendix 2 – Municipalities with relative high risk for elderly pedestrian accidents – Age Adjusted Standardized Accidents Ratios (ASEAR>100 per municipality type).

Municipality type	Observed accidents > Expected counts, ranked by risk size	Location	Percentage of riskier municipalities by type
Urban Areas	Umeå	North (Norrland)	26%
	Solna	Center (Svealand)	
	Malmö	South (Götaland	
	Huddinge	Center	
	Lund	South	
	Skövde	South	
	Norrköping	South	
	Luleå	North	
	Botkyrka	Center	
	Sundbyberg	Center	
	Trosa	North	
	Tidaholm	South	
	Boden	North	
	Stockholm	Center	
	Munkfors	Center	
	Lidköping	South	
	Tibro	South	
	Kristianstad	South	
	Sundsvall	North	
	Mariestad	Center	
	Karlstad	South	
	Karlskoga	South	
	Danderyd	Center	
	Göteborg	South	
	Höör	South	
	Lomma	South	
	Hammarö	South	
	Burlöv	South	
	Västerås	Center	
Accessible rural	Skellefteå	North	30%
	Arvika	Center	
	Ängelholm	South	
	Nyköping	Center	
	Kungälv	South	
	Vännäs	North	
	Falköping	South	
	Skara	South	
	Bjurholm	North	
	Alingsås	South	
	Örkelljunga	South	
	Gullspång	South	
	Klippan	Center	
	Torsby	Center	
	Karlsborg	Center	
	Örnsköldsvik	North	
	Enköping	Center	
	Oskarshamn	South	
	Båstad	South	
	Årjäng	Center	
	Töreboda	Center	
	Tomelilla	South	
	Hässleholm	South	

	Simrishamn	South	
	Vara	South	
	Västervik	South	
	Eslöv	South	
	Nässjö	South	
	Skurup	South	
	Vårgårda	South	
	Eksjö	South	
	Valdemarsvik	Center	
	Norrtälje	Center	
	Sala	Center	
	Sunne	South	
	Mönsterås	South	
	Herrljunga	South	
	ÖstraGöinge	South	
	Söderköping	Center	
	Värnamo	South	
	Sollefteå	North	
	Grästorp	South	
	Vetlanda	South	
	Hagfors	Center	
	Sävsjö	South	
	Hörby	South	
Remote rural areas	Norsjö	North	23%
	Robertsfors	North	
	Vindeln	North	
	Nordmaling	North	
	Ragunda	North	