Acute injuries resulting from accidents involving powered mobility devices (PMDs)—Development and outcomes of PMD-related accidents in Sweden

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\section*{ABSTRACT}

\textbf{Objective:} Powered mobility devices (PMDs) are commonly used as aids for older people and people with disabilities, subgroups of vulnerable road users (VRUs) who are rarely noted in traffic safety contexts. However, the problem of accidents involving PMD drivers has been reported in many countries where these vehicles have become increasingly popular.

The aim of this study is to extract and analyze national PMD-related accident and injury data reported to the Swedish Traffic Accident Data Acquisition (STRADA) database. The results will provide valuable insight into the risks and obstacles that PMD drivers are exposed to in the traffic environment and may contribute to improving the mobility of this group in the long term.

\textbf{Methods:} The current study is based on data from 743 accidents and 998 persons. An analysis was performed on a subset of data (N=301) in order to investigate the development of accidents over a period of 10 years. Thereafter, each accident in the whole data set was registered as either single (N=427) or collision (N=315).

\textbf{Results:} The results show that there was a 3-fold increase in the number of PMD-related accidents reported to STRADA during the period 2007–2016. With regard to single accidents, collisions, as well as fatalities, the injury statistics were dominated by males. Single accidents were more common than collisions (N=427 and N=316, respectively) and the level of injury sustained in each type of accident is on par.

The vast majority of single accidents resulted in the PMD driver impacting the ground (87%), due to either PMD turnover (71%) or the driver falling out of the PMD (16%). The reason for many of the single accidents was a difference in ground level (34%, typically a curb).

Cars, trucks, or buses were involved in 67% of collision events; these occurred predominantly at junctions or intersections (70%).

Abbreviated Injury Scale (AIS) 3+ injuries were dominated by hip and head injuries in both single accidents and collision events.

\textbf{Conclusions:} The present study shows that further research on PMD accidents is required, with regard to both single accidents and collision events. To ensure that appropriate decisions are made, future work should follow up on injury trends and further improve the quality of PMD-related accident data. Improved vehicle stability and design, increased usage of safety equipment, proper training programs, effective maintenance services, and development of a supporting infrastructure would contribute to increased safety for PMD drivers.

\section*{Introduction}

Road safety is a challenge of epidemic proportions. With 1.25 million people killed on the world’s roads each year and another 20–50 million seriously injured, road traffic injuries have become a public health priority whose social and economic implications extend well beyond the transport sector. (World Bank 2017, p. 6)

The European Commission (2017) reported that 25,500 individuals died on European Union roads during 2016 and estimated that 135,000 suffered serious injuries. In Sweden in 2017, out of a population of 10 million, 253 individuals were fatally injured and 4,400 seriously injured in accidents involving at least one moving vehicle in the traffic environment (The Swedish Transport Administration 2018a). Since 1997, traffic safety measures in Sweden have been based on what is commonly referred to as the Vision Zero charter, which has successfully contributed to reducing the number of vehicle occupant fatalities (Belin et al. 2012; Johansson 2009; The Swedish Government 1997).

Vulnerable road users (VRUs) are defined in the Intelligent Transport Systems (ITS) Directive (2010) as “non-motorised...
road users, such as pedestrians and cyclists as well as motorists and persons with disabilities or reduced mobility and orientation” (p. 4). According to the European Commission (2017), VRU transport accounts for the same proportion of road fatalities as cars (46%). VRUs, such as pedestrians and cyclists, for whom efforts at enhancing traffic safety are still facing major challenges, have steadily been attracting more attention (The Swedish Transport Administration 2017, 2018b; World Health Organization 2009, 2015).

A subgroup of VRUs, rarely noted in traffic safety contexts, are drivers of motorized mobility scooters (MMSs) and powered wheelchairs (PWCs), known as powered mobility devices (PMDs). These drivers are often elderly or persons with physical impairments or chronic diseases. MMSs can be hired in large supermarkets and shopping centers and at tourist attractions and visitor centers and are widely available for purchase from particular distributors as well as second-hand (Thoreau 2015). In recent years, young people are increasingly using them for leisure (Li and Chirwa 2014). PMDs enhance independence, promote engagement in daily activities, and improve social interaction (Auger et al. 2010; Brandt et al. 2004; Edwards and McCluskey 2010; Löfqvist et al. 2012; Samuelsson and Wressle 2014; Stenberg et al. 2016; Sund and Brandt 2017). The importance of PMDs has been highlighted in several international studies, including studies from New Zealand (Sullivan et al. 2014), Australia (Cassell and Clapperton 2006; Edwards and McCluskey 2010; Fomiatti et al. 2014; Jancey et al. 2013; Kitching et al. 2016; May et al. 2010; Nitz 2008; Oxley and Whelan 2008), Scandinavia (Baekgaard et al. 2017; Brandt et al. 2004; Hagberg et al. 2017; Löfqvist et al. 2012; Pettersson et al. 2016; Salminen et al. 2009; Samuelsson and Wressle 2014; Stenberg et al. 2016; Sund and Brandt 2017), The Netherlands (Cordes et al. 2018; Jannink et al. 2008; Leijdesdorff et al. 2014), Canada (Auger et al. 2010; Korotchenko and Hurde Clarke 2014; Ripat et al. 2015; Ripat and Colatruiglio 2016; Smith et al. 2016), the United Kingdom (Thoreau 2015), and the United States (Calder and Kirby 1990; Hoenig et al. 2007; Kirby and Ackroyd-Stolarz 1995; Ummat and Kirby 1994; Xiang et al. 2006).

International studies of PMD-related accidents have reported various types of personal injuries, such as to the feet and legs (Leijdesdorff et al. 2014; Paparone 2013) or head and brain (Baekgaard et al. 2017; Leijdesdorff et al. 2014). An Australian study found that 88.3% of fatal injuries among MMS drivers resulted from collisions with motor vehicles or falling off the MMS (Kitching et al. 2016), whereas Koppel et al. (2018) focused on fatal crash circumstances among older road users in general. As reported by Cassell and Clapperton (2006), falls were the cause of all MMS-related fatalities as well as half of MMS injuries treated in hospital. Collision with objects on pathways or cars and stumbling on uneven surfaces or curbs represent other major reasons for injuries requiring hospital treatment. An Irish study describes upper limb fractures among 3 elderly novel MMS drivers (Murphy et al. 2014). A literature review from New Zealand concluded that "operators of mobility scooters appear to be at significantly greater risk of being in an accident, and of being seriously or fatally injured in accidents, than other groups using the road corridor" (Newman 2015, p. 2).

However, knowledge and awareness concerning acute PMD-related accidents and injuries in the traffic environment are limited. Hence, the aims of this study were to analyze national PMD-related accident and injury data reported to the Swedish Traffic Accident Data Acquisition (STRADA) database, to perform an analysis of the development over a period of 10 years and investigate crash circumstances and risk factors. The results will provide valuable insight to the risks and obstacles that PMD drivers are exposed to in the traffic environment and may contribute to improving the mobility of this group in the long term.

METHODS

Data collection—STRADA

Relevant data from PMD accidents/injuries were extracted from the STRADA database. The national information system, STRADA, contains data on traffic accidents and injuries sustained within the Swedish road transport system provided by the police and emergency hospitals.

Including emergency hospital records in the study enhances the understanding of the type, as well as severity, of injuries sustained. Furthermore, hospital data reduce the number of accidents unaccounted for and increase police insight into certain categories of road traffic accidents (in particular, accidents involving VRUs such as pedestrians, cyclists, and moped riders). Police records generally contain information not included in hospital reports; for instance, the exact circumstances and environment in which a traffic accident occurred.

STRADA is administered by the Swedish Transport Agency. Early trials of the database were initiated in 1999, and reports have been received regularly by the police nationwide since 2003. In 2003, STRADA obtained data from 29 hospitals; this number has gradually increased, to 68 hospitals in 2012 and 71 hospitals in 2016.

Because the STRADA database lacks specific variables regarding PMD type of vehicles, in order to identify relevant cases, what is generally referred to as a free-text search was performed. The keywords used for this search were “electric wheelchairs” and “mobility scooters” plus synonyms. The search resulted in a total of 783 unique accident identities compiled in an Excel file; that is, accidents involving 1,137 persons during the period January 1, 2001, to May 31, 2017.

Data analysis

Information from all 783 accident cases and 1,137 persons were systematically analyzed using Excel in the 4 phases described below (Figure A1.1, see online supplement). The statistical study was limited to a simple descriptive analysis.

- The first phase involved removing data concerning 40 accidents/73 persons from the data set because they were not considered relevant to the scope of the study.
Consequently, the current study is based on data from the remaining 743 accidents and 998 persons.

- The second phase involved performing a development analysis on a subset of data to investigate whether the annual number of accidents involving PMDs is increasing, decreasing, or at a consistent level. Sweden is divided into 21 different hospital regions; each region joined STRADA at different times between 2000 and 2016 (Figure A1.2, see online supplement). Inclusion criteria for the development analysis stipulate that a hospital region must have been fully reporting to STRADA during the 10-year period 2007–2016, which qualified 10 hospital regions and 301 accidents.

- The third phase involved registering each accident in the whole data set as either single (N = 427) or collision (N = 316):
  - Single accident events were categorized as turnover (the PMD tipped over), fall off (the PMD driver fell off the vehicle), impact (the PMD impacted a fixed object), or miscellaneous (Table A1.1, see online supplement). In cases where the PMD first impacted a fixed object and consequently turned over, it was registered as turnover (i.e., not registered as an impact). The circumstances of a single accident event were categorized as curb, terrain (i.e., ditch), fixed object (i.e., road barrier), surface (i.e., road work, pothole, ice/snow), collision avoidance (i.e., avoiding impact with another road user may have resulted in a turnover), speed (i.e., excessive speed while turning may have resulted in a turnover), and miscellaneous (Table A1.1).
  - Collision events were categorized as truck/bus, car, motorcycle/moped, bicycle, pedestrian, or miscellaneous (Table A1.1). The circumstances of an event were categorized as zebra crossing, crossing, road section, car park, combined foot path and cycle lane, footpath (including pavement), or miscellaneous (Table A1.1).
  - For both single accidents and collisions, injured body region(s), injury severity, and other relevant parameters were categorized in accordance with Table A1.1. The Injury Severity Score (ISS) is defined as the sum of squares of the highest Abbreviated Injury Scale (AIS) score in each of the 3 most severely injured body regions, with one exception; the ISS score was automatically computed as 75 for individuals sustaining an injury of AIS 6 severity (the maximum ISS possible; MacKenzie 1984; Stevenson et al. 2001). The injury severity was categorized as uninjured, minor (ISS 1–3), moderate (ISS 4–8), severe (ISS 9–), fatal, and unknown, in accordance with the STRADA registry.
  - The fourth phase included dividing collision events into VRU collisions (N = 103) and collisions with cars/trucks/buses (N = 210). For VRU collisions, injured body region(s) and injury severity were analyzed for the PMD driver as well as the counterpart (N = 108).

**Results**

**10-Year development**

Data were extracted for from 10 hospital regions in Sweden for the period 2007–2016, as indicated in green in Figure A1.2. In total, 301 accidents were included, and their distribution is depicted in a scatterplot (Figure 1). As seen in the plot, there was a 3-fold increase in the number of PMD accidents during 2007–2016.

**Single accidents (N = 427)**

The vast majority of single accidents (87%) resulted in the PMD driver impacting the ground—either due to PMD turnovers (71%) or the driver falling off the PMD (16%; Figure 2a). In 9% of cases the PMD impacted a fixed object. Turnover was typically caused by a difference in ground level, uneven surface, excessive speed while turning, or unexpectedly entering the surrounding terrain. A fall from the PMD typically occurred due to a sudden stop or an unpredicted motion/movement of the PMD. In total, 34% of single accidents were caused by a difference in ground level (typically a curb), 9% by entering the terrain, 11% by impacting a fixed object, and 10% due to surface conditions (unevenness, poor maintenance, etc.; Figure 2b).

Severe injury (ISS 9–) was registered in 13% of cases, moderate (ISS 4–8) in 24%, and minor (ISS 1–3) in 57%; the remaining 3% of cases were uninjured (Figure 3, Figure A1.3a, see online supplement). Fatal outcome was registered in 10 cases (2%), all of which involved elderly males (77 ± 9 years old = average ± 1 SD). The body region most commonly injured in single accidents was the head (32%), followed by upper limbs/arms (26%), lower limbs/legs (19%), hip (9%), and torso (8%; Figure A1.4a, see online supplement). AIS 2+ injuries were most frequently located in the arm (31%), head (25%), leg (19%), and hip (16%; Figure A1.4c, see online supplement). AIS 3+ injuries were dominated by hip (40%) and head (29%) injuries (Figure A1.4e, see online supplement).

**Collisions (N = 316)**

The collision counterpart most often was a car (60%), followed by a pedestrian (18%), bicycle (9%), truck/bus (7%), or motorcycle/moped (5%; Figure 4a). More than half of the accidents (53%) occurred while crossing a road (35% zebra crossing; 18% crossing; Figure 4b). Pedestrians, cyclists, and moped and motorcycle drivers (VRUs; N = 103; Figure A1.6a, see online supplement) were most often involved in PMD collisions on combined foot paths/bicycle lanes (32%), footpaths (26%), crossings (17%), or road sections (10%; Figure 4b).
A1.6c, see online supplement). Cars, trucks, and buses (N = 210; Figure A1.6b, see online supplement) were most frequently involved in PMD collisions at zebra crossings (51%), crossings (19%), or road sections (18%; Figure A1.6d, see online supplement). These vehicles reversed into the PMD in 9% of cases. Fatal injury was registered in 4% of cases, severe (ISS 9–13) in 4%, moderate (ISS 4–8) in 12%, and minor (ISS 1–3) in 56% of the remaining cases were uninjured and 16% were unknown (Figure 3; Figure A1.3b, see online supplement).

In VRU collisions, data regarding injured body region and injury severity were extracted for the PMD drivers (Figures A1.6e, A1.7a, A1.7c, A1.7e, see online supplement), as well as the counterpart (Figure A1.8, see online supplement). Among PMD drivers, 24% were uninjured, 25% sustained minor injuries, 2% sustained moderate injuries, and 1% sustained severe injuries; however, a large number remain unknown (48%; Figure A1.6e). More information was available for their counterparts (5% uninjured; 61% minor, 15% moderate, 3% severe, and 1% fatal injuries; 16% unknown; Figure A1.8a, see online supplement). Thus, data indicate that the VRU counterpart is more likely to be injured than the PMD driver. Only sparse information was available for the PMD drivers and counterparts, respectively, with regard to injured body region (85 and 50% unknown; Figures A1.7a, A1.8b, see online supplement). For the counterpart, leg injuries accounted for 25%, followed by arm (12%) and head (5%); AIS 2+ injuries were dominated by leg (50%) and arm (31%) injuries (Figures A1.8b, A1.8c, see online supplement).

In car/truck/bus collisions, 71% of the PMD drivers sustained minor injuries, 16% sustained moderate injuries, 5% sustained severe injuries, and 6% of injuries were fatal (Figure A1.6f, see online supplement). Nine of the 12 fatalities involved males (75%), and they were all elderly (80 ± 11 years old). Information regarding injured body region was missing in 36% of cases; the known cases were evenly distributed over the head, arms, legs, hip, and torso (Figure A1.7b, see online supplement).

In most cases, the unavailability of information regarding injury data was due to the accident only being recorded by the police; that is, not by any hospital. In some cases, data were missing because only one of the parties involved in the collision was recorded in STRADA (see "not reported" in Figure A1.1).

### Other parameters

PMD accidents occurred more frequently during the summer than during winter, especially in single (38% compared to 12%) and VRU (49% compared to 12%) collision events (Figures A1.5a, A1.9a, see online supplement). Thus, 3.2 times more single accidents occurred during summer compared to winter; the corresponding number was 4.2 for VRU collisions. Car/truck/bus collisions were more evenly distributed over the year (Figure A1.5a, see online supplement). PMD collisions were more common during weekdays and relatively few PMD collisions occurred on the weekend (especially Sundays), whereas single accidents were more evenly distributed over the week (Figures A1.5b, A1.9b, see online supplement). PMD accidents occurred most frequently during the daytime (81%), between 10 a.m. and 6 p.m., and rarely during late evenings or at night (Figures A1.5c, A1.9c, see online supplement).

The analysis revealed that almost twice as many males (62%) as females (38%) were involved in PMD single accidents. Similar differences were found between male (55%) and female (32%) PMD drivers involved in collisions; however, gender was unknown in some cases (13%), probably due to only the VRU counterpart being injured. Interestingly, the majority of VRU counterparts were females (females 59%, males 25%, unknown 16%). Such gender differences were especially prominent among pedestrians, where 77% of the counterparts involved were females (males 19%; unknown 3%).

The average age of PMD drivers involved in collisions was 64 ± 18 years (median 67 years) and the average age of PMD drivers involved in single accidents was 67 ± 18 years (median 71 years; Figures A1.5d, A1.9d, see online supplement).
Discussion

Research on PMD drivers has traditionally been focused on usage, based on the ability of disabled individuals to maneuver a scooter and the significance of the vehicle for everyday quality of life. Previous research has also studied the construction and design of PMDs, as well as discriminatory physical barriers and challenges in the environment. The present study provides another perspective by using national traffic injury data (STRADA) on acute traffic-related injuries involving PMDs in hospital emergency departments in Sweden. This is in line with the Vision Zero charter, which was adopted by Sweden 20 years ago (The Swedish Government 1997).

The results of this study reveal an increase in the development of PMD-related accidents reported to STRADA (Figure 1). Similar trends have been observed for wheelchair users in the United States (Xiang et al. 2006) and MMS users in The Netherlands (Leijdesdorff et al. 2014) and Australia (Cassell and Clapperton 2006; Gibson et al. 2011). It is likely that the rising proportion of elderly persons will contribute to a further increase in the numbers of PMDs, as reported by Canadian, Australian, U.K., and U.S. studies (House of Commons Transport Committee 2009; Jancey et al. 2013; LaBan and Nabity 2010; Mortenson and Kim 2016) and will thus likely increase the number of PMD-related accidents. In addition, several studies have reported that accidents and incidents are common and likely underestimated (Chen et al. 2011). According to a survey in southern Sweden, 15% of drivers were involved in some kind of accident or incident in the form of turnovers or collisions (Carlsson 2007). An Australian study showed that 21% of respondents had experienced accidents or incidents during the past year (Edwards and McCluskey 2010). A study from Taiwan found that 55% of respondents (including both manual and powered wheelchair users) had experienced at least one accident during the last 3 years (Chen et al. 2011). Furthermore, the results of this study showed that PMD-related single accidents occurred more often than collisions (57 and 43%, respectively). Similar findings have been reported for other types of VRUs in Sweden, such as pedestrians (96% single accidents, 3% collisions; Berntman 2015) and cyclists (72% single accidents, 27% collisions; Thulin and Niska 2009).

Single accidents require further research because data from the present study revealed that moderate injuries (ISS 4–8) occur 2.7 times, serious (ISS 9–15) 4.6 times, and fatal virtually as often as in collisions (10 and 12, respectively; Figure 3). The vast majority of single accidents resulted in the PMD driver impacting the ground (87%), either due to PMD turnovers (71%) or the driver falling out of the PMD (16%; Figure 2a), which is in agreement with earlier reports (Calder and Kirby 1990; Cassell and Clapperton 2006; Gaal et al. 1997; Xiang et al. 2006). Xiang et al. (2006) concluded that turnovers and falls are the leading cause of injuries among wheelchair users across all age groups in the United States. Calder and Kirby (1990) found that in 77% of wheelchair-related deaths, the user had been subject to a turnover or fall. Cassell and Clapperton (2006) reported that all MMS-related fatalities and around half of hospital-treated injury cases were caused by falls. Furthermore, the body region most commonly injured in single accidents was the head (32%, Figure A1.4a), which makes sense considering the great share of drivers impacting the ground. In a study of 30 individuals who fell from a wheelchair, Opalek et al. (2009) found that severe head and brain injuries were the most common injury in turnovers and falls. In this study, hip and head injuries dominated the AIS 3+ injuries in both single accidents as well as collisions (Figures A1.4e, A1.4f, see online supplement).

Collisions involved cars, trucks, or buses in 67% of cases (Figure 4a) and predominantly occurred at junctions or intersections (70%; Figure A1.6d). The findings are (partly) in line with reports from previous studies (Cassell and Clapperton 2006; Gibson et al. 2011; LaBan and Nabity 2010; Mortenson et al. 2017). Gibson et al. (2011) reported that most MMS-related fatalities were the result of collisions with a motor vehicle, and the most common cause of death was a head injury. Furthermore, a large proportion of fatalities was found to have occurred while crossing a road, attempting to alight from the scooter, and entering or approaching intersections. LaBan and Nabity (2010, p. 558) found that limited visibility played a significant role because most of the collisions occurred between dusk and dawn and involved a vehicle larger than a conventional car. In addition, questions were raised whether some of the collisions between PMDs and motor vehicles were “sitting suicides” (LaBan and Nabity 2010, p. 558).

Gender differences were found in the injury statistics in both single accidents (62% males; 38% females) and collisions (55% males; 32% females; 13% unknown). Even larger proportions were reported in PMD collisions involving motor vehicles in the United States, where males were more often involved than females (3:1 ratio; LaBan and Nabity 2010). Furthermore, male PMD drivers dominate the statistics in fatal outcomes (87% males; 13% females); similar results have previously been reported for car drivers in Sweden (84% males; 16% females), cyclists (88% males; 12% females) and motorcyclists (95% males; 5% females; The Swedish Transport Administration 2018a). An Australian study confirmed the results, stating that males are significantly overrepresented in mortality data related to MMSs (74% males; 26% females; Gibson et al. 2011). One contributing factor may be that more males drive PMDs than females. According to a Swedish study, the proportion of males using PMDs is 1.5–2 times that of females (Pettersson et al. 2016), which corresponds well with a U.S. study stating that more than two thirds of PMD users are males (LaBan and Nabity 2010). Another contributing factor may be that females and males experience their use of the PMDs differently (Pettersson et al. 2014). However, a reverse gender ratio was found in the present study in cases where the PMDs were involved in collisions with pedestrians, where female pedestrians dominated the injury statistics (19% males; 77% females). It would be interesting to further investigate these gender differences in more detail.

Human factors are important to study because PMD drivers are a multifaceted subgroup of VRUs, which may contribute to an increased complexity in injury prevention strategies. Previous research has highlighted the importance of proper training in managing the PMD (Cassell and Clapperton 2006;
Cordes et al. 2018; Jancey et al. 2013; Jannink et al. 2008; Mortenson and Kim 2016; Mortenson et al. 2017; Murphy et al. 2014; Nitz 2008; Opalek et al. 2009; Toosiзадeh et al. 2014). Because many PMD drivers experience difficulties maintaining an upright seated posture when subjected to external forces, seat belts and leg rests have been strongly recommended (Cooper et al. 1998; Corfman et al. 2003). In PMD turnover tests, greater head impact forces and Head Injury Criterion (HIC) values were recorded for an unbelted Hybrid III dummy (6,181 ± 2,372 N; HIC = 610 ± 634) in comparison to a belted dummy (1,336 ± 827 N; HIC = 29 ± 38; Erickson et al. 2016). However, Chen et al. (2011) found a low usage rate of safety equipment among manual and powered wheelchair users; 70.5% were unbelted and 61.1% did not use antitippers. Some studies propose helmet usage for PMD drivers (Baekgaard et al. 2017; Gibson et al. 2011) and compare the importance of helmet usage in reducing traumatic brain injuries among other VRUs, such as motorcyclists and moped and scooter drivers (Baekgaard et al. 2017). Cassell and Clapperton (2006) suggested that potential benefits of using seat belts, helmets, and gloves should be further investigated.

Vehicle factors include the vehicle’s technical performance, function, and construction, such as brakes, engine, electronics, mechanics, and wheels, as well as safety equipment, adjustments, and stability (Kirby and Ackroyd-Stolarz 1995). The PMD needs to be visible and detectable by other road users; for example, through lights, reflexes, or sound. However, concerns have been raised regarding the lack of safety features such as flags, lights, reversing indicators, and seat belts (Gibson et al. 2011). Technical issues with PMDs have been reported in studies from Australia, Sweden, and the United States (Carlsson 2007; Edwards and McCluskey 2010; Gaal et al. 1997; Gibson et al. 2011; Kirby and Ackroyd-Stolarz 1995). One third of participants in a U.S. study reported component failure (Gaal et al. 1997). Problems with tires and batteries were highlighted in an Australian study; a third of respondents said that they were worried that the battery would discharge while away from home (i.e., range anxiety; Edwards and McCluskey 2010). Several participants in a Swedish study claimed that a wheel had fallen off (Carlsson 2007). Furthermore, the stability of the PMDs when negotiating curbs, uneven surfaces, or snowy roads is a major challenge, considering the relatively narrow base of support, high center of gravity, and small wheel size (Corfman et al. 2003; Gaal et al. 1997; Gibson et al. 2011). Kirby and Ackroyd-Stolarz (1995) found that turnover in the forward direction was most common in PWCs, whereas turnover in the sideways direction was most common in MMSs. More research is strongly recommended to improve the performance of these vehicles in outdoor conditions.

Environmental factors that need to be considered are infrastructure design/configuration and road maintenance. Gibson et al. (2011) identified the physical environment as a powerful factor influencing safe motorized mobility scooter use. Duvall et al. (2016, p. 209) reported that “many public pathways are sufficiently rough to result in harmful vibrations and discomfort for wheelchair users.” Corfman et al. (2003, p. 180) stated that “although the constructed environment is critical to the EPW user’s safety, guidelines as to its design have been based largely on accessibility and physiologic data rather than on safety considerations.” The present study, as well as previous research, identified curbs as a major obstacle and cause of accidents for PMDs (Corfman et al. 2003; Edwards and McCluskey 2010; Erickson et al. 2016). The question arises as to why pavements (with curbs) are designed the way they are and whether there are alternatives for separating pedestrians from other road users while simultaneously safeguarding effective drainage and guidance for the visually impaired. Inadequate snow/ice clearance may severely restrict mobility and cause difficulties in the daily lives of people with disabilities. The low injury rate during winter compared to summer in the present study may indicate less outdoor activity among PMD drivers during the winter, which is in agreement with previous studies from Denmark and Canada (Brandt et al. 2004; Steyn and Chan 2008). Furthermore, because 70% of PMD collisions involving a car, truck, or bus occurred at intersections, as found in the present study, it would be a challenge to construct safer crossings that would make PMDs more visible to other road users. However, with recent developments in the field of active safety (i.e., autonomous brakes), the risk of this type of collision will likely decrease. Another way to improve mobility and independence among PMD drivers would be to facilitate recharging the vehicles in the urban environment.

Social/system factors are important to consider in order to decrease the risk of accidents for this particular type of vehicle and road user. This may include activities of the PMD users, appropriate prescription by health care professionals, proper training programs, and effective and adequate maintenance routines, as highlighted in previous studies (Chen et al. 2011; Kirby and Ackroyd-Stolarz 1995; Xiang et al. 2006). In addition, the PMD needs to be properly adjusted to fit the driver (Corfman et al. 2003). Chen et al. (2011) found that individuals who failed to maintain their wheelchairs regularly and used wheelchairs not prescribed by professionals had significantly greater risk of accidents. It is of great importance that maintenance of PMDs is as efficient and available as possible, because the vehicle can be regarded as an extension of the body for disabled people. Unnecessarily long maintenance times may result in PMD users failing to maintain the PMD properly if it means that they will not have freedom of movement for an extended period of time. Thus, the performance and function of the vehicle will eventually deteriorate.

One limitation of this study is the lack of specific variables regarding PMD types in the STRADA database; there is no unified way of categorizing these vehicles. PMDs can be categorized as pedestrians, mopeds, other vehicles, or bicycles. A free-text search was performed in order to identify relevant cases; hence, there is a risk that cases might have been overlooked due to different spelling or vocabulary in the database. Similar findings were reported by LaBan and Nabity (2010, p. 557), who wrote that “an initial survey of police reports was immediately frustrated by an inability to separate motor vehicle and electric mobility device collisions from the much
larger group that involved ambulatory citizens because both types were classified together as ‘pedestrian accidents.’”

The present study has shown that more in-depth research on PMD-related accidents is needed, with regard to both single accidents and collision events. Future work should follow up on injury trends and further improve the quality of PDM-related STRADA accident data—for example, by adding a category specifying whether any aids were used—in order to take appropriate action. Improved vehicle stability and design, increased usage of safety equipment, proper training programs, effective maintenance services, and development of a supporting infrastructure would all contribute to increased safety and mobility for PMD drivers.

In summary:

- There is an increase in the number of PMD-related accidents in Sweden. A further increase is expected due to an aging population and the growing popularity of PDMs.
- Single accidents are more common than collision events, and the injuries are at least as serious. The vast majority of single accidents resulted in the PMD driver impacting the ground.
- Males dominate the injury statistics in single accidents, collisions, as well as fatal outcomes.
- The majority of AIS 3+ injuries were hip and head injuries in both single accidents and collision events.
- To improve the safety of PMD drivers, different perspectives must be considered, such as human, vehicle, and environmental factors (in accordance with Haddon’s matrix), as well as social factors (as they pertain to these types of vehicles).

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