Analysis of conflict situations between elderly pedestrians and vehicles

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Abstract - The proportion of older road users is increasing because of demographic change (in the group 65+ from current 18% to about 24% by 2030). The mobility needs of people 65+ often differ from those of younger people. Seniors (65+) are already more involved in fatal accidents than younger road users. According to the age development, the senior share of road deaths in the EU of today is increasing nearly one-fifth to one-third.
From the in-depth analysis of accidents generic simulation models were developed. Attention has been paid both to psycho-physical characteristics as well as on the social and physical environment and their specifics in conjunction with seniors. By simulating the defined scenarios and varying the defined relevant parameters, accident influencing factors were examined as a basis for avoidance. In addition, the parameters were varied to show the influence from the vehicle, the pedestrian and the infrastructure to avoid the accident or to characterize the conditions for which the accident is inevitable.

INTRODUCTION

The proportion of older road users is increasing because of demographic change (in the group 65+ from current 18% to about 29% by 2050 [1]). The mobility needs of people 65+ often differ from those of younger people. Although a high proportion of private motorized transport, also, unlike younger, a high share of foot traffic can be seen for the elderly. Seniors (65+) are already more involved in fatal accidents than younger road users. According to the age development, the senior share of road deaths in the EU of today is increasing nearly one-fifth to one-third. Seniors die mostly as weaker road users: the proportion of senior pedestrians killed is about 40% [2]. This bear seniors themselves in very few cases the blame, they behave at pedestrian crossings defensive (they leave relatively more vehicles pass than younger road users, before they cross.). Particularly for the elderly a reduction of muscle activity and the sense of balance can be observed, it comes to poor eyesight, elderly people have difficulty requiring divided attention and the useful field of view (UFOV) decreases with age. The modeling of a pedestrian takes place mostly on measured average speeds, but from observations it can be seen that the movement consist of different sections (for example when crossing a road: lane entering, accelerating, constant speed, decelerating, lane exit), with different tasks concerning attention.

METHOD

In a statistical analysis of traffic accidents, with special attention to elderly persons, types of accidents were categorized with data from Statistics Austria as basis. The traffic accidents were prepared and their statistical relevance was analysed.
The behaviour and the perception of older pedestrians was analysed. This was done based on analysis of the literature and through focus group interviews with the target group. In addition, a behaviour and interaction observation at selected sites and analysis of social space was carried out.
For an in-depth analysis of traffic accidents CEDATU (Central Database for In-Depth Accident Study) was analysed in detail. Through an in-depth analysis the corresponding relevant scenarios, including their impact parameter (e.g. speed, infrastructure, visibility, but also subjective elements such as impairment of perception of the persons or communication problems between the involved, etc.), were set. The accidents were grouped according to main parameters such as the direction of movement, etc.. The accidents were analysed from the perspective of the pedestrians and of the driver and out of this generic accident scenarios were generated, taken into account the potentially different judgments of the different road users groups.
For the simulation of generic scenarios the findings of the in-depth analysis and social area analysis were included and out of these simulations safety parameters for different accident scenarios were

derived. From the variation of safety parameters for different accident scenarios, measures were analysed and the potential of individual measures were discussed (in terms of vehicle, pedestrian and infrastructure).

RESULTS

Accident analysis

In a descriptive analysis of traffic accidents corresponding types of accidents with a focus on older road users have been categorized. These accidents were analyzed and displayed their statistical relevance. Data basis of this analysis was traffic accident data from Statistics Austria for the years 2002 until 2011 [3]. In Figure 1 it can be seen, that the fatality rate for the 65+ age group is high. From the data of Statistics Austria it is evident that traffic accidents involving pedestrians 65+ often cause fatal (Figure 1) and serious injury. Likewise, it can be concluded that the risk of being involved in a traffic accident as a pedestrian, significantly increases from the seventieth year. A person aged 80-84 years has a threefold higher risk than a person of the age group 35-39 years to be injured through a pedestrian accident. Due to population projections by Statistics Austria, in which the proportion of 65+ people will rise by up to 50% in the next twenty years, this problem will accumulate.

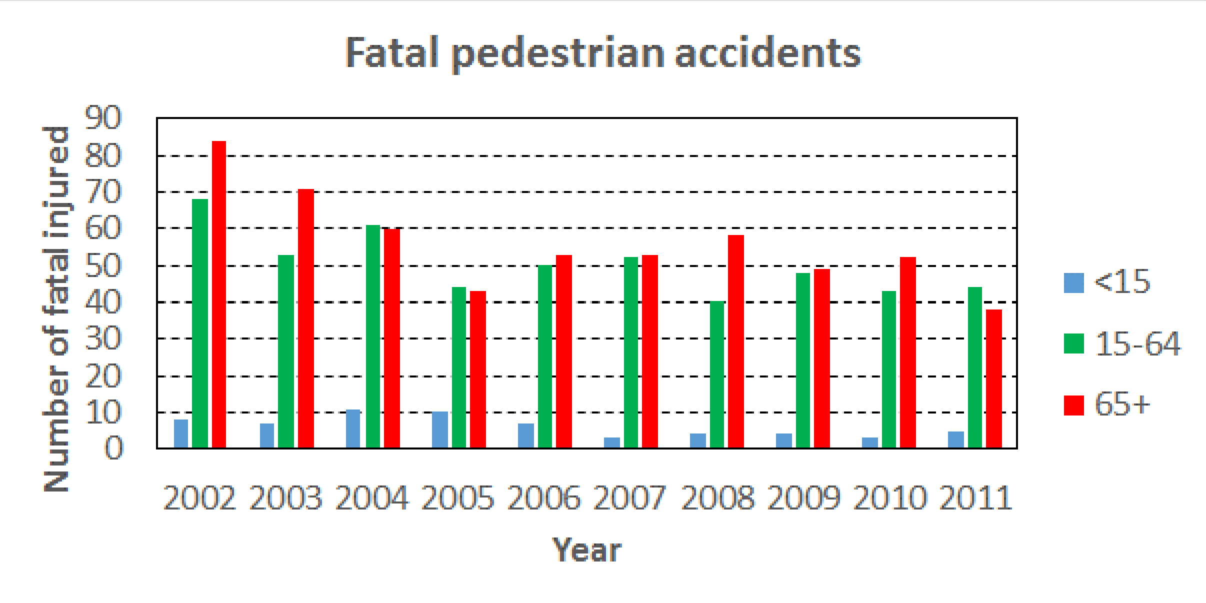


Figure 1. Fatal pedestrian accidents in Austria for different age groups

In actual figures for Austria from 2002 to 2011 it can be seen that the proportion of female victims is about 66%. The traffic accident occurred more than 90% in urban areas. 60% of accidents with injured pedestrians occur on open sections and 40% at intersections.

In case of accidents on open road traffic accident in which the pedestrian tries to cross from the left or right is dominant. Higher than average are also the type of accident, in which a pedestrian 65+ collides with a reversing vehicle (15.8%; Ø7.8%), and over-represented is the type of accident, in which the pedestrian 65+ collides with a vehicle at a house or estate driveway (14.3%; Ø6.9%). The information on average is on basis of total pedestrian accidents on Austria's roads over the period 2002-2011. Above average are accidents with pedestrians aged 65+, in which the driver turns left and the pedestrian tries to cross the road from right to left (18.8%; Ø14,1%). Fatal injuries occur also due to the higher speed, mainly in the crossing area when the vehicle maintains its direction and thereby collides with a pedestrian.

In-depth-Accident analysis

An in-depth analysis carried out on basis of data from CEDATU (Central Database for In-Depth Accident Study) [4, 5]. The accident distribution corresponds and is linked to the national Austrian accident statistics. Relevant factors from the pedestrians perspective were: ‘non- or insufficient attention to the traffic’, ‘influence of alcohol’ or ‘worn no reflective material". The lack of reflective material is due to the fact that especially fatal 65+ pedestrian accidents most frequently occurred in the dark or dusk in the winter months of November and December. For the vehicles sight the influencing factors are: ‘insufficient attention to the traffic’, ‘inattention/distraction’ or especially ‘incorrect behavior towards pedestrians at pedestrian crossings’. Also the influence factor ‘alcohol’ was present in the used dataset. For the walking speeds of the pedestrians, it can be stated that in 65% of the cases it was less than 5 km/h at time of collision. Walking or running speeds of more than 9 km/h could not be determined. Regarding the reaction of the driver it should be mentioned that in less than 50% of the cases there was a reaction before the collision.

Interaction and Perception

Focus group discussions, which were part of the project, showed on the one hand, the expected abundance of individual and collective experiences of older pedestrians in traffic, and on the other hand, substantiated the results of international studies in this field of research.

These potentially critical situations mainly concern crossing situations. A very dangerous situation seems to be immediately after entering the roadway. Although older pedestrians take more time to go off the curb than younger people (also referred as ‘curb-delay'), older pedestrians need much longer time to cross the first lane. This in combination with a potentially limited perception and an increased requirement for differentiated primary and secondary actions can lead to significant errors and misjudgments. Here the individual skills play a significant role. Accordingly important is the infrastructural condition, because older pedestrians take more attention to the condition of the roadbed to handle any barriers, obstacles or unevenness. In addition problems for older pedestrians are out of home mobility and route selection. Furthermore intersections are a major problem. This is due to the fact that they have to cross the road, especially at intersections, and on the other hand older people are often overwhelmed with the higher complexity (multiple lanes, different groups of road users and traffic sign) at intersections in urban areas.

The problems older pedestrians are faced in public space generally and road transport in particular are infrastructure-related aspects, interaction problems and social issues. In the context of infrastructural problems causes of negative reviews and negative experiences are mainly signaling, marking and unevenness. There is a need for clear signaling which also takes into account the potential sensory impairments of the older age groups and also visibility and perceptibility under low light conditions and low contrast play a significant role. They need unique markings of the various traffic areas to counteract potential critical situations. The more clearly especially crossing scenarios are designed, the higher is the subjective sense of safety, not just for the elderly pedestrians. The marking should be designed accordingly and visible, where to move, where to cross the road, where the curb is and where the curb ends. This should be identifiable clearly and under different weather and light conditions.

Moreover, especially the prevention of falls and the fear to be further restricted in their own independence and quality of life was an important and clear message when performing focus group interviews.

The perception of these aspects requires everyday mobility considerably and, subsequently, the routes as pedestrians. To move safe in public spaces, both the routes and the surrounding circumstances, e.g. climate and weather, are considered. Generally, those places are avoided in the route selection, which are subjectively unsafe, because either the volume of traffic is high, in terms of individual motorized traffic as well as in relation to other pedestrians and cyclist. Thus the perceived ability to come into conflict is high. In summary the safety-related mobility behavior is mainly dependent on own skills and experience. Critical events are primarily in connection with prevention and compensation of falls. The infrastructure and the behavior of other pedestrians affect behavior and perception of older road users more than safety considerations.

Pedestrian model

In general older people are involved more often in accidents in urban areas. Older pedestrians are often involved in accidents at intersections. For vehicles that turn there is often an attention conflict or older pedestrians are often overlooked or not perceived correctly. Crossing wide roads is a challenge for older pedestrians, especially complex situations generates problems. Vehicles performing not 'normal' driving maneuvers such as turning and backward moving are often perceived wrong or are misinterpreted. Functional impairments often produces time pressure, leading to risky actions. The risk of falling is a crucial component for older pedestrians in which the attention is partly focused on fall prevention and the traffic is neglect.

The problem for the development of a simulation model for older pedestrian is that there are no common parameters which are valid in general. Aging can be described and there are effects that occur earlier or later, however, these effects are also dependent on a number of factors that have ostensibly nothing to do with a road use. From the literature, aging is described with an increase of deficits in sensory, motor, cognitive and perceptual range. One characteristic of aging is the slowing down of processes, which is caused mainly by central cognitive processes, but they are partly also described as a change in the sensory faculties that do not supply the brain with enough or the right information or slower nerve transmissions.

To navigate in traffic it requires a large number of capabilities and features to solve complex situations. Many of these abilities decrease with age or performing complex tasks is difficult. Thus, for example, estimating of speeds and distances is mentioned, the ability to generate preparatory information and process suggestions, to make decisions and to react appropriately to situations. It is also described that information can not be processed in parallel easily but are increasingly being carried out sequentially. Functional tasks, which have to be handled are seeing, hearing, walking and attention in general. With age, deteriorate senses and weak motor skills can cause falls and be a significant health risk. On the subject of attention arise increasingly difficulties especially in situations that requires divided attention.

Oder and Grayson [6] define six relevant tasks that the pedestrian has to handle when crossing the road:

- Selection of a suitable location
- Selection or setting the time needed
- Traffic observation
- Evaluate traffic
- Find a suitable gap
- Crossing

Generic Scenarios

The appearance variety of people on the roads is large, the movements are highly dynamic, visibility is often restricted by occlusions (parked vehicles, infrastructure, etc.) and the relevant accident scenarios are very complex. Comparing the population with the pedestrian accidents by age group, there is a significantly increased risk of accidents especially in the age group 80+. From the age of 65+ more risk is shows for accident involvement or to be injured or killed in an accident.

For the scenarios there is a clear tendency to pedestrians accident in urban areas with more than 90% in case of accidents on the open road and 97% at intersections. For the scenarios especially crossing scenarios are relevant. From the statistics it is shown accident scenarios dominate (more than 70% of fatal accidents) in which the involved pedestrians crosses the road from the left or right. Other relevant scenarios are collisions at house or estate driveway, collision with a reversing vehicle and collision with a turning vehicle.

International studies have also analyzed the increased risk of elderly pedestrians. Fontaine and Gourlet [7] concludes in a French study that most accidents involving older people (65+) occur in the middle or at the end of the road with respect to the transverse direction but for children more accidents happen at the beginning of crossing. More than half of the 65+ pedestrian accidents occurred when crossing from left to right with respect to the vehicle, in the other age groups the majority of accidents could

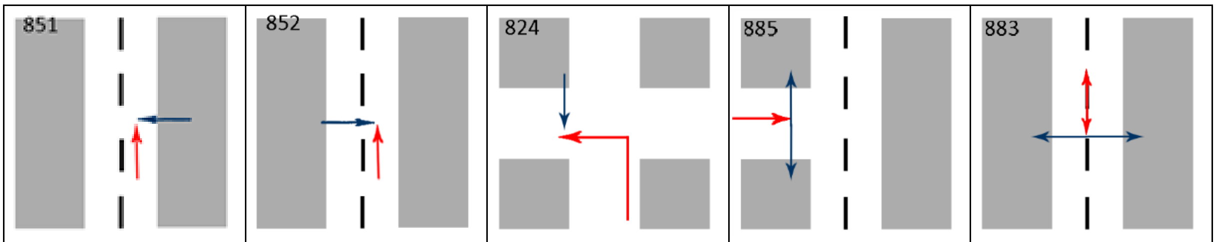
be seen when crossing from right to left. They justified this with the lower speed of the elderly and their difficulty to respond to critical situations. An alternative explanation is that older people are less able to consider two traffic streams due to reduced attention capacity.
An accident analysis based on the German In-Depth Accident Study (GIDAS) for identifying relevant accident scenarios with pedestrian or cyclist participation and focusing on scenarios with severe injury (MAIS2 +) and in urban environment [8] found the majority of cases for

- crossing pedestrians on a straight road with good visibility (59.0%)
- crossing pedestrians on a straight road with sight disability (27.4%)
- crossing pedestrian in connection with a turning maneuver of the vehicle (7.1%)

The EU project Vruits (Improving the safety and mobility of vulnerable road users through ITS applications) [9] defined scenarios from the analysis of databases of other EU projects (WATCH OVER, SafetyNet, PENDANT, Road Safety Observatory ERSO, Dacota). For the pedestrian accident, they identified the most common scenario when pedestrians cross the street on the open road (away from an intersection)

- crossing nearside (45.9%)
- crossing nearside, but covered by parked vehicle (14.4%)
- crossing far side (23.8%)
- crossing far side, but covered by parked vehicle (8.4%)

An Australian study [10] dealt with the impact of collisions from reversing vehicles with vulnerable road users (particularly pedestrians and cyclists). An analysis of GIDAS (German In-Depth Accident Study) data was performed for this study. The results showed that of 68 reverse-collisions on public roads and highways, pedestrians were the most involved, with a share of 45% of all car collisions and 48% of truck accidents. 70% of the injured were women and 74% were over 60 years old. In Australia resulted for KSI (killed or seriously injured) accidents with reversing vehicles that adults, especially the elderly, were affected.
Based on literature review, real accident situations and the parameters determined from the in-depth analysis, a generic simulation model was created. By simulating the defined scenarios and varying the relevant parameters influencing parameters could be identified and examined as a basis in terms of avoidance for the vehicle, the pedestrian and the infrastructure. By varying these parameters the influence was investigated in order to avoid the accident or identify the conditions for witch the accident is inevitable.
The selected scenarios were crossing from left and right on open sections and at intersections with and without crosswalk, and reversing and turning vehicles.



Collision when crossing from left	Collision when crossing from right	Collision with turning vehicle	Collision with a vehicle at driveway	Collision with reversing vehicle

Figure 2. Generic accident scenarios

Crossing a road
Crossing a road is a critical moment for older pedestrians, and it has been shown that they often try to cross the road, although the time period for a safe crossing is too short (Oxley et al. [11]). A partial explanation for this misconception is that older people tend to judge the distance, instead of the

vehicle speed (Lobjois and Cavallo [12]). Another risk factor in this assessment process could be that older pedestrians underestimate how long they need for crossing the street. Holland and Hill [13] performed traffic simulator experiments to identify factors for decisions and examined time estimates. An age-related effect was independent of gender, people in the age group 25-59 were the most precise, in the age group 60-74 underestimation of the time was most often, while people in the age group 74+ overestimate the passing time. They reasoned these effects with the lack of ability of the consideration of physical impairments that contribute to the lower walking speed. Important in this context is the discrepancy between the actual and estimated walking time, which resulted in this context, with a higher proportion of unsafe crossings and lower margins.
Another study from Zivotofsky et al. [14] on real, 7 m wide roads, showed the age group about 70 years underestimated their passing time, while younger people were accurate. Curbs prepare older road users problems, however, there are few studies to quantify the behavior. A study of Knoblauch et al. [15] showed that the curbs led to longer passing time and this effect tends to increase with age.

Gap selection
The crossing of a road is a complex task, to analyze the behavior of older pedestrians in traffic is a key point for understanding of the role of perceptual, cognitive and motor factors. The deficits that win importance with aging, especially the perception and judgment of distance and speed is a challenge and have been partially analyzed. Investigations by Oxley et al. [16] showed that many accidents occur with the elderly in crossing the road. Elderly often do not see the vehicle, with which they collide or when they see the car, they assume that the driver saw them and would perform an evasive or braking maneuver. For the pedestrian assuming an average walking speed of 1.4 m/s (about 5 km/h) for adults and 0.9 m/s (3.2 km/h) for older pedestrians, different times, which are necessary for crossing the road arise depending on the width of the road. It can be seen that for the crossing of a single lane with 3 m the pedestrian needs 2.2 (2.7 for elderly) seconds, which is the mean value. It has to be considered that persons moving faster and slower, but the risk for people with impairment and younger people is higher, because they have on the one side to compensate their impairment or on the other side, they have not enough experience or skills. The gap between vehicles has to be, for 30 km/h traffic and a walking speed of the pedestrian of 5 km/h and a lane with of 3.5 m, 2.5 seconds (the time needed for the pedestrian to cross the lane) respectively 21 m (the distance the vehicle travels during that time) (Figure 3). If there is a road with two lanes with oncoming traffic, for the second lane the pedestrian has also to select a gap with these minimum requirements, but at time of starting the crossing the gap on the other side has to be in a distance of 21 m (Figure 4).

Vehicle							Pedestrian						
	Braking (t_r = 0.8 s; t_l = 0.2 s)												
v [km/h]	a_{br} =3 m/s², Distance [m]	a_{br} =3 m/s², Time [s]	a_{br} =5 m/s², Distance [m]	a_{br} =5 m/s², Time [s]	a_{br} =8 m/s², Distance [m]	a_{br} =8 m/s², Time [s]	Walking speed [km/h]	1. lane width [m]	Time to cross [s]	Gap needed [m]	2. lane width [m]	Time to cross [s]	Gap needed [m]
30	19.1	3.7	14.4	2.6	11.8	1.9	5.0	3.5	2.5	21.0	3.5	5.0	42.0
							3.2	3.5	3.9	32.8	3.5	7.9	65.6
40	30.6	4.6	22.3	3.1	17.7	2.3	5.0	3.5	2.5	28.0	3.5	5.0	56.0
							3.2	3.5	3.9	43.8	3.5	7.9	87.5
50	44.6	5.5	31.8	3.7	24.5	2.6	5.0	3.5	2.5	35.0	3.5	5.0	70.0
							3.2	3.5	3.9	54.7	3.5	7.9	109.4
60	61.3	6.5	42.8	4.2	32.3	3.0	5.0	3.5	2.5	42.0	3.5	5.0	84.0
							3.2	3.5	3.9	65.6	3.5	7.9	131.3
70	80.5	7.4	55.3	4.8	41.1	3.3	5.0	3.5	2.5	49.0	3.5	5.0	98.0
							3.2	3.5	3.9	76.6	3.5	7.9	153.1
100	153.6	10.2	102.1	6.5	73.2	4.4	5.0	3.5	2.5	70.0	3.5	5.0	140.0
							3.2	3.5	3.9	109.4	3.5	7.9	218.8

Figure 3. Gap selection of pedestrian to cross the road

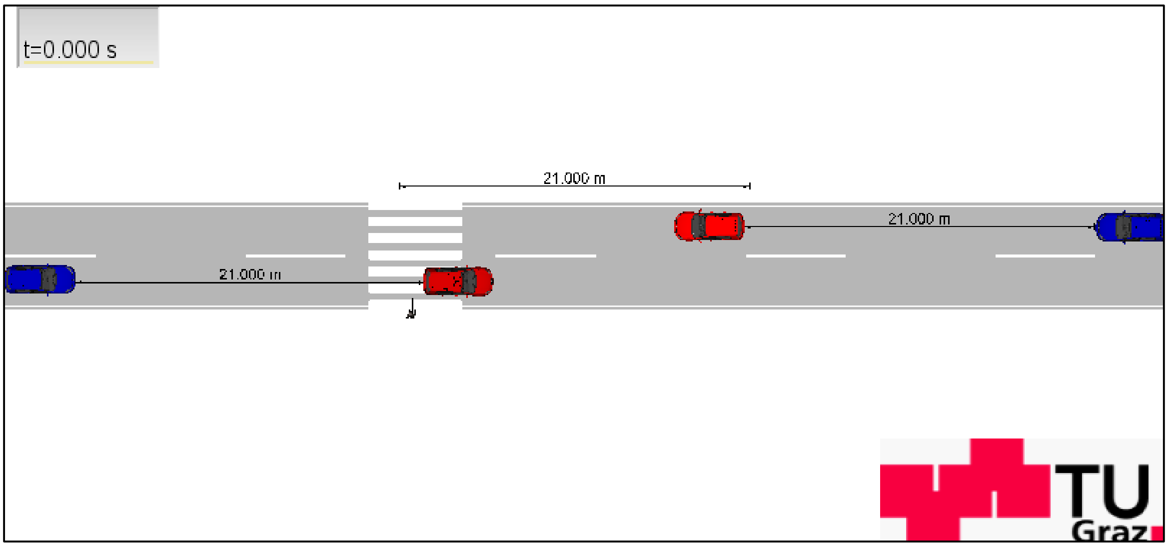


Figure 4. Gap selection of pedestrian to cross the road

This means that if the pedestrian is wrong with the estimation of the distance of the vehicle a great danger arises for a collision. It is known that elderly have difficulties with the estimate of distances or velocities. Especially elderly with restricted eyesight rely on noises or compensate sight disorder with hearing.

Parameter velocity

Normal walking is more difficult with age and therefore the walking speed is slow. Asher et al. [17] determined the average speed for older male adults with 0.9 m/s and for women over the age of 65 years with 0.8 m/s. Bohannon et al. [18] found in a meta-analysis (with 23 000 volunteers) younger adults over a distance of 4 to 30m an average speed of 1.43 m/s.

This is problematic if for the design of pedestrian crossings typically a walking speed of about 1.2 m/s is used. In addition to the above data, older adults have also increased accident involvement on wider streets (Zegeer et al. [19]), which is an indication that the fragility is a factor. The walking speed is an important factor in the simulation of unsafe crossing (Holland et al. [20]).

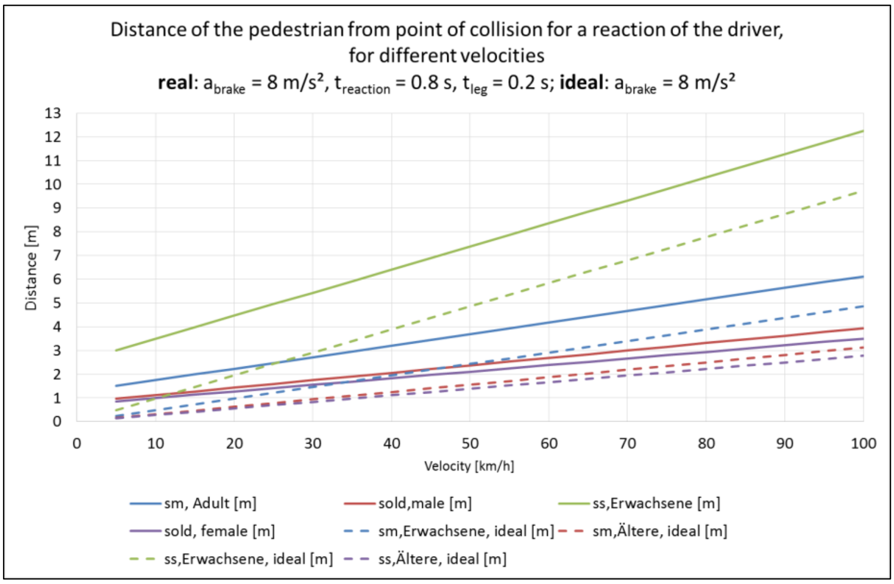


Figure 5. Distance of the pedestrian from point of collision for a reaction of the driver, for different velocities

In Figure 5 the distances of the pedestrian from point of collision for a reaction of the driver for different initial velocities with a reaction time of 0.8 seconds, a brake leg time of 0.2 seconds and a brake deceleration of 8 m/s² are plotted. This means that for a road with allowed speed of 50 km/h the driver has to detect the pedestrian with a walking speed of 0.9 m/s ($s_{old, male}$, 3.2 km/h, red graph in Figure 5) in a transverse distance of 2.4 m to stop the vehicle before the crossing line. In Figure 5 also the distances for the mean walking speed of adults ($s_{m, adult}$, walking speed 5 km/h, blue), the fast walking speed of adults ($s_{f, Adult}$, walking speed 10 km/h, green) and walking speed of old females ($s_{old, female}$, walking speed 2.9 km/h, purple). This results in the situation that theoretically a higher speed of the pedestrian is more difficult to be processed, because they have to be recognized in a wider distance. But by the greater speed they require a shorter time for the crossing. Under ideal conditions, i.e. no reaction time and no leg time, it follows that the avoidance for an accident with an adult pedestrian is possible with a vehicle speed of approximately 10 km/h and with an old pedestrian up to an initial speed of 25 km/h, if the pedestrian can be recognized when he is in a transverse distance of 1 m to the drive line of the vehicle. The values relate to a maximum deceleration of 8 m/s², that is a dry road surface, and an ideal system configuration with no reaction time required and the maximum deceleration is achieved immediately upon the start of braking.

Parameter acceleration
From observations and the literature it is known that the road crossing is not a homogeneous event. As already mentioned, the avoidance of falling is a significant aspect for older pedestrians. Therefore the speed is reduced when entering or leaving the road, especially if curbs or bumps have to be overcome. A study of Naveteur et al. [21] showed that for volunteers 75+ the curb costs on average about half a second for crossing a road of about 7 m, 25% of these participants needed more than one second longer for the crossing with curbs than without. This can have a huge impact when the lower walking speed of the elderly is considered. For example, at a two-lane road with 3.5 m width and a permitted speed of 50 km/h first a gap of about 55 m for the nearby traffic has to be selected. For the far side lane at a distance of more than 180 m an additional gap of at least 55 has to estimated, assuming that the vehicle does not brake in time (Figure 3). In addition, there are, as described above, adverse effects such as reduced vision or concentration on the ground, to avoid falls, and as an additional aspect the reduction of the walking speed when leaving the curb or when e.g. tram rails have to be passed.

Parameter infrastructure
As already known from the accident analysis, many accidents occur in situations where the driver has no clear view of the pedestrian because they are covered e.g. by parked vehicles, trees, etc.. The main influencing factors are road design, geometry of crossing, crossing opportunities, lightning, signals, marking, weather, public transport (e.g. stopping place) and town planning.
There are a number of possible actions with positive effects, such as spatial separation by underpasses and overpasses. Design of the stops of public transport, appropriate design of the area for the pedestrian, e.g. guide through structural measures, relocation of stops to avoid coverage, lighting, etc..
At locations where pedestrian have to cross multilane roads with high speeds and heavy traffic, the following countermeasures may be effective to reduce the frequency and severity of pedestrian accidents

- create crossings possibilities
- lead pedestrian so that they cross at corresponding locations
- design of the entrances from the sidewalk, e.g. curb ramps, which are on the one hand facilitate the crossing of the road and are perceived easier for visually impaired pedestrians by tactile design. They should be performed perpendicular to the road and guide the pedestrian (e.g. colors and architecture design) and enable the access the for disabled people.
- lighting of the corridor
- traffic calming measures such as speed limits, narrowing lane, etc.

Multi-lane roads with increased traffic are a problem especially for older pedestrians. Traffic islands act as pedestrian refuges, providing an opportunity to pause, during the crossing of several lanes. This also allows the finding of suitable gaps in order to cross the road safely. They should be of sufficient width and length corresponding to offer pedestrians movement ability and time to be able to safely wait until they find a suitable gap for crossing.
Sidewalk encourage not only to walk, but also improve significantly the safety of pedestrians. On roads without sidewalks pedestrians are forced to walk along the edge of the road, which increases the risk of accidents.

Parameter vehicle and driver
There are many influencing factors related to the vehicle and the driver, which often are decisive for an accident but are also often occur in combination with other factors and lead to an accident. An influence have the vehicle fleet such as the proportion of large vehicles, the speed, the vehicle design as well as electric vehicles by the reduced noise. An important factor is the driver, with the parameters skills, education, experience, distraction, unsafe driving, speed selecting, alcohol and drugs. The vehicle technology has an influence, especially the increasing proportion of active systems, and it can be expected that they partially improve the situation.

CONCLUSION

An important step in pedestrian planning is to identify critical sites and prioritize them. A systematic approach is necessary to find out what (and where) countermeasures should be taken. Factors such as speed, friction and the available space will be used as criteria for the quality of motorized traffic. These factors, however, are not the primary factors for pedestrians, but much more comfort, mobility and safety.
The question of the responsibility of the driver is not always clear. The basic premise is that the driver performs his duty of care towards pedestrians. But also the pedestrians have to comply with the care for their own safety and the safety of others. Therefore also awareness campaigns on pedestrian safety and relevant laws, training and education of the drivers and the pedestrian are components for improving safety.

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