Assessment of Pedestrian Fatality Risk at Unsignalized Crosswalks by Means of Simulation

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Abstract Unsignalized crosswalks are one of the most critical/risky traffic infrastructures in terms of safety, due to potentially vehicle-pedestrian conflictual interactions. Many accidents occur there and elderly pedestrians are among the most vulnerable victims. In a previous work, a simulation model has been developed with the aim of predicting traffic volumes and waiting times by reproducing the behavior of pedestrians and drivers during crossing attempts. Calibration and validation was performed based on experimental data gained through a field observation in an area with a significant population of elderlies. In this paper, we are focusing on safety issues and the simulation model has been adapted to include collisions between vehicles and pedestrians. The new simulation model presented here allows to compute the risk of an unsignalized crosswalk by considering both frequency and gravity of collisions. We consequently used the simulation model to evaluate the efficacy of particular policies. Simulation results show that while speed limit enforcement has an important effect in reducing pedestrian causalities, alternative and indirect solutions aiming at improving drivers' awareness are also effective to improve safety.

1 Introduction

Traffic safety has seen a rapid improvement during the 20th century and the number of road fatalities has constantly decreased in the developed countries [9]. However, improvements in terms of traffic victims and injuries are becoming minimal and with the aging of population, elderly are increasingly the most vulnerable among the different road users. The "World report on road traffic injury prevention" high-

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lights "pedestrian safety as the main safety concern for the elderly", thus suggesting that pedestrians infrastructures need to be designed with a particular attention when elderly are the largest users. Among the several infrastructures making up the pedestrians environment, the crucial point where vehicles and cars interact in a direct way is represented by the case of unsignalized crosswalk, which is responsible for a comparatively high number of fatalities compared to other facilities.

Although there have been several studies considering experimental aspects of the behavior of both drivers and pedestrians on crosswalks, simulation models have been more limited in number. Some early studies considered crosswalks as purely mathematical model, allowing to determine for example the mean vehicle queue length, but were not able to consider the heterogeneity found in human behavior [5]. In the recent years, the popularity of computer simulation has brought some more sophisticated models which allows to consider more subtle aspects of crossing behavior, such as walking outside the zebra crossing [10]. In our previous work, we also proposed a simulation model which predicted with sufficient agreement the Level of Service (LOS) and traffic volumes [3, 1].

However, although some statistical models can be found in the literature [8], none of the simulation models presented so far consider collisions between vehicles and pedestrians, thus limiting their field of application to traffic engineering excluding safety issue. In this paper, we present a simulation framework (based on a validated model) which allows to consider collisions in a systematic way. Since microscopic data on traffic accidents are not available (usually only aggregated data for cities or countries are provided), we were not able to validate results for accidents, but qualitative nature of the results showed some agreement with real situations.

2 Simulation model

2.1 General architecture and motion rules

The simulation is based on a hybrid environment which employes different approaches for vehicles and pedestrians. A Floor Field Cellular Automata model is used to simulate pedestrians in their environment (sidewalk and crosswalk) and a modified Gipps model is used to account for the motion of vehicles (details are given in [3]). Fig. 1 provides a schematic image providing details on the geometry considered. Dimensions for the simulated scenario have been chosen equal to a crosswalk selected during an on-field observation carried out in the city of Milan (Italy) in an area characterized by a large elderly population and by a high number of pedestrian-car accidents in the past years [4].

Pedestrians are randomly generated from one of the four corners and get randomly assigned destinations which force them to cross the road. Cars move in a periodic environment along two lanes with opposite direction. The interaction between vehicles and pedestrians is modeled according to the logic of Fig. 2.

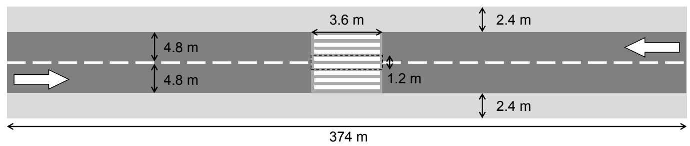
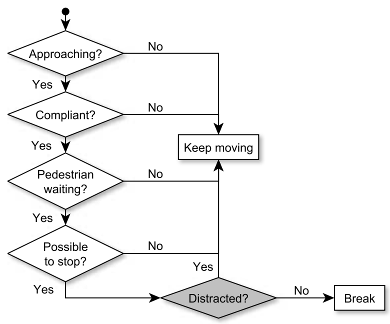
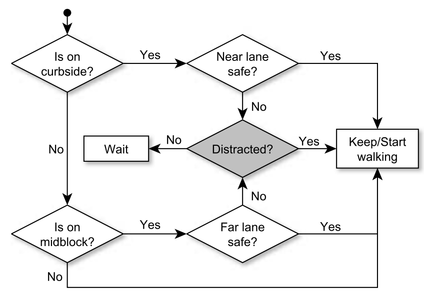


Fig. 1 Geometry considered in simulation and its size (midblock is given in dotted lines).



(a) Vehicle flowchart



(b) Pedestrian flowchart

Fig. 2 Decision making process for pedestrians and vehicles in relation with crosswalk.

Drivers consider the possibility of breaking before the crosswalk only if they are leading a group of vehicles (i.e. approaching the crosswalk), they are compliant (i.e. the driver is willing to stop) and one or more pedestrians are waiting. Next, it is computed if the car can physically stop and this calculation is based on the kinetics law of the Gipps model. Pedestrians follow a similar behavior: when reaching the curbside they will check if a car is approaching and if it can stop. If the close lane is safe they will cross until the midblock (a virtual area in the middle of the road) and repeat the decision making process again for the far lane. This crossing action was adopted after noticing a similar behavior during the on-field observations (i.e. appraising phase for evaluating the safety gap from oncoming vehicles).

To account for collisions, a given portion of drivers or pedestrians neglect the existence of the respective counterpart. This is to reproduce the risky behavior typically observed in case of collisions (or conflicts). For pedestrians, Hatfield and Murphy [6] found that about 3% of the people crossing the road at unsignalized crosswalks were looking at their phone and did not pay attention to traffic conditions. We can assume a similar proportion of users are distracted in our simulation.

It is important to notice that in our model there is a difference between *non-compliant* and *distracted* drivers. Distracted drivers do not break even if a pedestrian is on the road, while non-compliant ones will not stop when a pedestrian is on the curbside but will always stop if a pedestrian is already crossing.

With the aim to keep the simulation model relatively simple, we did not model the possible occurrence of accidents among vehicles; so, drivers have the ability to perceive other vehicles even if they are marked as distracted.

2.2 Estimation of collision gravity

Next, there is an additional important aspect which needs to be considered on collisions between vehicles and pedestrians and it is related with the fatality risk. It is known that collision speed has a strong relationship with the probability of resulting in pedestrian's death. Age of the pedestrians is also relevant, with elderly being more vulnerable then adults due to their body fragility. To quantify the relationship between collision speed, pedestrian age and fatality risk, several authors collected data relative to traffic accidents and obtained a function describing this probability. Davis [2] presented a function which can be used to compute the risk of fatality as:

$$p_{fatality} = 1 - \frac{e^{a-b\cdot v}}{1+e^{a-b\cdot v}} \tag{1}$$

where v is the collision speed (relative to the vehicle) and a and b empirical parameters obtained by fitting with statistical data for traffic accidents (in the case of Davis, data are relative to the 1970s when safety was rather poor compared to current standards). Different parameters have to be used depending on the age group of the pedestrian involved and Davis estimated them for children, adults and elderly.

To measure pedestrian risk in a particular crosswalk using the simulation model, it is not sufficient to simply count the number of collisions occurring, but gravity of the accidents also need to be accounted for. We therefore decided to include the above equation for pedestrian fatality in our model and evaluate each collision between vehicle and pedestrian using it. Our results will be therefore based on the combination between the frequency of collisions and the gravity of them, meaning that a crosswalk where collisions occur relatively often at low speed may be considered more safe than a crosswalk where collisions are rare but usually result in pedestrian death.

3 Results and discussion

To reduce the number and relevance of accidents between vehicles and pedestrians, policies are an effective measure. The "World report on road traffic injury prevention" [9] estimated that serious and fatal road casualty reduction effects related to new policies account for 42% in the case of pedestrians, the highest percentage among road users. We want therefore to investigate which policy is the most efficient in reducing road casualties related to the specific case of pedestrians crossing unsignalized crosswalks. Our model allows to change different parameters related to traffic conditions and pedestrian/driver's attitude. The standard values used for the simulation results presented hereafter are given in Table 1.

For each simulation we varied the parameter which had to be investigated and kept the remaining ones constant. Since the case of elderly pedestrians is an important part of this work, three different scenarios were considered: adults-only, a

Table 1 Values used in the simulations presented in this work. In each case a single parameter was varied by keeping the remaining ones constant.

Type	Variable	Value
Driver's attitude	Car speed	40.0 km/h
	Non-compliance	0.5
Traffic conditions	Car density	15.0 $(\text{km/lane})^{-1}$
	Pedestrian flow	5.0 min^{-1}
Distraction	Distracted pedestrians	0.02
	Distracted drivers[a]	0.00

[a] When amount of distracted drivers was varied, distracted pedestrians was set at 0

population consisting of adults and elderly in equal amount and elderly-only. If not provided in Table 1, values were taken from the on-field observation or from the literature (and are given in [3]). Pedestrian safety was estimated computing the cumulative fatality risk over the total simulated time (360 hours) and finally summarizing it in term of fatalities per hour.

3.1 Driver's attitude

We can start by considering driver's attitude, for which speed and non-compliance are given in Fig. 3. Logarithmic scale is used since fatality risk contains exponential terms and changes in fatality risk are extremely quick in a limited speed range.

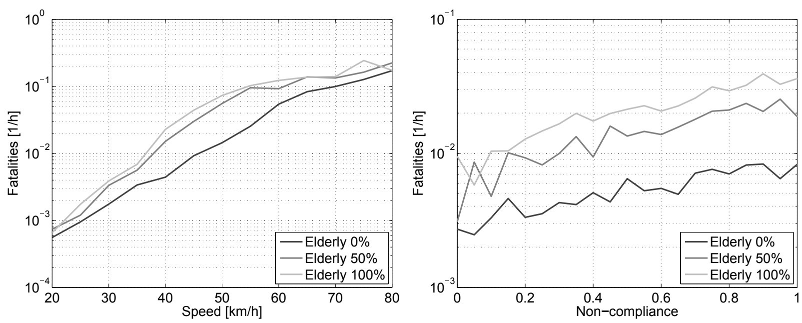


Fig. 3 Relationship between drivers' attitude (in terms of speed and compliance) and fatality risk for crossing pedestrians.

A first look on both graphs should suggest that fatalities are intuitively high. Although it is not possible to provide a direct comparison with empirical data, from the graph for speed it is obtained that at 50 km/h one fatality occurs roughly about every 4 days (or almost 90 fatalities per year). To understand these results it is important to remark that parameters used refer to a moderate level of traffic from both vehicles and pedestrians and simulations were performed with the level of traffic unchanged for 360 hours (i.e. constant during day and night). Also, parameters used for the fatality risk are relative to the 1970s. The results presented here are therefore intended for comparison between different policies and for qualitative considerations. Quantitative values are to be handled with care.

The graph for speed shows that velocity clearly has an influence on pedestrian fatality for all the populations considered. The ratio of elderly roughly has a linear relationship with frequency of fatality (consider that logarithmic scale is used). On the other side, non-compliance is seen as having only a marginal effect of pedestrian safety. Qualitatively it can be observed that pedestrians are able to recognize non-compliant drivers, thus preventing them from having a collision with them. In this regard, it can be concluded that compliance becomes important for LOS considerations, but its relation with safety is limited.

3.2 Traffic conditions

Next we wish to consider volumes of traffic for both vehicles and pedestrians, whose simulation results are given in Fig. 4.

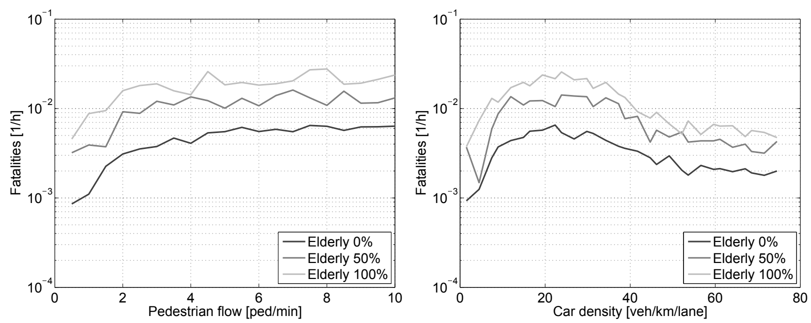


Fig. 4 Relationship between traffic volumes for vehicles and pedestrians and fatality risk for crossing pedestrians.

In the case of pedestrians, it is shown that fatalities grow with the volume of traffic, but a plateau is reached for around 6 $(\text{min})^{-1}$. This could be related with the fact that when the traffic of pedestrians grows, it is more often observed that people have to wait at the curbside. As a consequence even if a distracted pedestrian crosses without checking, it is more likely that cars already stopped to give way to other pedestrians, thus preventing him/her from suffering an accident. In the case of vehicular traffic (more precisely density), the situation is slightly different. At first the number of pedestrian fatalities grows with an increase in car density, but after reaching a maximum at about 20 cars/km/lane, it constantly decreases until the maximum density considered in simulations. This sudden change was created by the formation of traffic jams which reduced the driving speed for cars consequently reducing the cumulative risk for pedestrians.

Considering traffic volumes of both pedestrians and vehicles altogether it can be concluded that a dense traffic is beneficial for pedestrian safety. This conclusions are in line to what is observed in the case of “shared spaces” (in which traffic signs are removed), where urban environment and traffic volumes create a reduction in speed, which is beneficial for the safety of pedestrian users. Karndacharuk [7] reported for a shared space area in the city of Auckland (New Zealand) that vehicle speed increased with a decrease in the number of interactions, making the area more safe during the day (when the number of interactions is higher) but more dangerous at night.

3.3 Distraction

Finally, we wish to consider distraction and in particular we want to investigate which road user is most dangerous when not paying attention to the other type of entity. Results are shown in Fig. 5. In each case, distraction was set at zero for the road user which was not varied to allow a comparison under equivalent conditions.

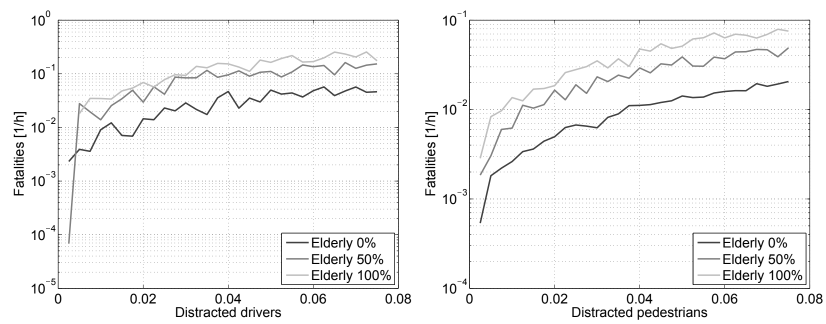


Fig. 5 Relationship between distraction in drivers and pedestrians and fatality risk for crossing pedestrians.

The general behavior is similar for both drivers and pedestrians, although distraction in drivers results in a number of fatalities 3–4 times higher compared to distracted pedestrians (although victims are always pedestrians). These results show that reducing the amount of distracted drivers is more effective than increasing awareness among pedestrians. Being the most vulnerable users, pedestrians are somehow responsible for their own safety regardless on the behavior of drivers, but results show that policies increasing awareness on traffic accidents are more effective when directed on drivers. In this regard, the use of shared spaces may help increasing the sense of responsibility among drivers possibly reducing their distraction.

4 Conclusions and discussion

Based on empirical results from a field survey, a simulation model for pedestrians crossing at unsignalized crosswalks was developed. Crossing mechanism of pedestrians has been modeled in a two-step fashion. A pedestrian attempting to cross will consider only the near lane first and later check the safety of the far one while walking on the crosswalk. The inclusion of distracted road users (not paying attention to traffic conditions) allowed to simulate accidents occurring between crossing pedestrians and incoming vehicles. Several scenarios were studied to investigate which factor is the most relevant in reducing fatalities and improving pedestrian safety. Speed limit was found being an effective measure to reduce fatality among pedestrians, since probability of surviving an accident is directly related to it. However, we also found that alternative solutions may have the same impact without specifically addressing only one road user. In particular, the shared space concept can automatically reduce traffic speed and, at the same time, decrease the number of distracted drivers, both leading to a safer pedestrian environment.

Acknowledgements This research was founded by the “AI*IA INCOMING MOBILITY GRANTS 2016”, the “University of Tokyo international students scholarship” and the SEUT-RA program.

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