A cross-study on video data gathering and microsimulation techniques to estimate pedestrian safety level in a confined space

Chiara Gruden\textsuperscript{1}, Tiziana Campisi\textsuperscript{2}, Antonino Canale\textsuperscript{2}, Giovanni Tesoriere\textsuperscript{2}, Matjaz Sraml\textsuperscript{1}

\textsuperscript{1}University of Maribor, Faculty of Civil Engineering, Transportation Engineering and Architecture – Smetanova 17, 2000 Maribor, Slovenia
\textsuperscript{2}University of Enna Kore, Faculty of Engineering and Architecture – Cittadella Universitaria 94100 Enna, Italy

gruden.chiara@gmail.com

Abstract. Nowadays, pedestrian safety is a growing problem: on the one hand pedestrian movement is increasing, on the other hand measures to improve walkers’ safety are still scarce. During the years, various behavioural models have been proposed, which consider several parameters characterizing both the environment and the road users. Many studies define accident risk as a combination of three main factors, which are the accident occurrence probability, the vulnerability of the involved users and the economic and social damages due to the accident. The approaches spotted in literature about pedestrian safety assessment are various and they mainly deal with vehicle-pedestrian accidents. These studies have been developed in order to foresee and reduce possible losses in human lives. Also pedestrian-pedestrian encroachments can lead to dangerous consequences, but researches about them are still limited. This study aims to highlight the correspondence and/or the differences between different analysis methods applied to pedestrian field, focusing on situations where no interactions with vehicular traffic exist. This is one step of a wider research, which has been carried out on a confined space, selected because of easy replicability of its general geometrical features and of the effects on pedestrian trajectories induced by some local peculiarities of the facility. The study focuses on the evaluation of a real case, which has been monitored through the use of cameras and analysed via a dedicated tool. The achieved results have been then compared to the outputs obtained by reconstructing the same situation in a micro-simulation model. The first step - video acquisition and elaboration - allowed to observe how people behave in the examined area and how the environment influences their trajectories, while the second phase permitted to understand if a microsimulation tool can reliably reply pedestrian movement in the analysed scenario and therefore provide surrogate safety values comparable to the ones obtained from real data. In the model, a simplified but still accurate environment has been set up: homogeneous geometric features have been drawn and no obstacles have been considered. The modelled pedestrian flow is a bi-directional, 2400 ped/h flux, characterized by heterogeneity of agents: both male and female adults. In order to be able to compare the data obtained by video footages and elaborated through an ad hoc tracking tool with outputs of the microsimulation model, from the whole flow on the ramp some intersecting pedestrians have been selected in both directions of walking. This cross-study of two different techniques has allowed to inspect the effects of the environment on pedestrian dynamics and to precautionary estimate the level of safety via calculation of surrogate safety parameters.
1. Introduction

Sustainability issues and green policies are looking at eco-friendly transport modes, i.e. walking and cycling, as good practice to minimize the use of private vehicles. A lot of nations are investing funds to improve road infrastructures, focusing their attention particularly on pedestrian areas, with the aim of ensure mobility to all pedestrian categories.

Also, several safety measures are realized, e.g. the setting of specific traffic signal cycles at road intersections, or the use of sensors to reduce waiting times in the areas characterized by high pedestrian and vehicular flows [1].

There are already some researches facing with pedestrian incidentally, different conflict types and the related consequences [2]. Sure, conflicts among pedestrians are rare events and normally they don’t cause serious damages. If these are positive features, they also do not allow to use traditional accidental data analysis to study them and to apply the results to daily traffic safety. Moreover, the high underreporting of this kind of accidental information [3] let data be not enough reliable for further analysis. The study of pedestrian trajectories and of their possible intersections could be a solution to the problem of data scarcity: indeed, these events are much more frequent and, starting by them surrogate safety can be estimated, where “surrogate” indicates that no accidents occurred [4].

Many researchers have focused their efforts on individuating elements influencing pedestrian safety: the geometry of a section and the more or less dense presence of other walkers in the same are two of the main factors affecting pedestrian behavior and consequently safety [5] [6]. In addition, gender, age and social aspects act a lot on pedestrian travelling speed and time, modifying their behavior [7] [8]. Urban areas have been mainly addressed as study locations to highlight how intersection geometry, as well as yielding behaviors and vehicular-pedestrian flow mix can impact on vulnerable road user safety [9] [10]. Recently, the attention has been turned on surrogate safety indicators: mainly time and speed measures – like TTC, PET and relative speed, well representing situations which can lead to possible dangerous conflicts [11]. These parameters are indeed able to describe and estimate different types of potential accidents, to count them and to provide optimal results to solve daily urban safety problems. In [3] a complete overview of the surrogate safety theory is introduced, while in [12] various techniques applying this theory are reported, as well as useful case studies. This pro-active approach, with all its advantages – first of all the opportunity of studying safety before an incident happens, has been widely applied to vehicular conflicts, some efforts have been spending on cyclist safety aspects [10], but still little works have been developed from pedestrian point of view.

The present work aims at assessing pedestrian safety in a surrogate manner, starting from video footages recorded on a small, crowded space. Via video elaboration real pedestrian trajectories have been evaluated. The estimation of the same scenario has been developed also through a pedestrian microsimulation tool and the infrastructure’s level of service as well as pedestrian simulated trajectories have been calculated. Finally, using the achieved trajectory data, surrogate safety parameters have been manually estimated and compared.

2. Methodology

To develop the research, a 4-step-procedure has been followed: the first step is the general geometrical analysis of the environment and the pinpointing of pedestrian flows walking on the facility; the second and third steps have been developed simultaneously and consist in the extraction and elaboration of real-world data on a side, and the micro-simulation of the selected environment on the other side; finally, the last passage is the comparison among the obtained results. The overall process is synthetically described in figure 1, where also some middle-steps of data gathering and simulation are noticeable. In the following sub-paragraphs, the practical development of the four steps is deeply described.
Figure 1. 4-step-procedure followed to develop the cross-comparison of the two selected methods to achieve surrogate safety indicators.

2.1. Location geometrical and flow analysis
The location selected for the study is a pedestrian ramp, which for its general features is an easily replicable environment, but it also shows peculiarities which can influence pedestrian movement of the facility itself. The geometrical analysis of the ramp allowed to obtain quantitative and qualitative information about the environment where pedestrians walks and to stress out elements, which can induce particular dynamics. It has been developed matching web mapping information, *.dwg drawings and visual observations. Considering the general environmental aspects, the ramp is a narrow and long area, similar to many other common facilities, like pedestrian bridges, sidewalks, etc. Observing the local features of the chosen infrastructure, some interesting structural peculiarities can be noticed, which could affect walkers’ actions: the facility is, indeed, characterized by a constant, ascending slope of 20%, it has a width of 4.0 m and a length of 9.0 m. For the whole length of the ramp there are some particularly shaped steps, built as kerbs and created with the aim of stopping the slipping feet of walking people. The kerbs’ extent equals the width of the bridge, i.e. 4.0 m, and they are 0.05 m wide. Between two consecutive kerbs a plane 4.0x0.3 m area is comprised. Looking at pedestrian flow features, the analysis has detected a very high, bi-directional and mixed flux, composed of both males and females. Different attitudes can be observed: a part of the flow make a lot of stops and delays, while the remaining people, probably commuters, try to exit the zone as faster as possible. Based on the general and local features of the facility and on the peculiarities of the flow, the location seemed well-fitting the aim of this research, allowing on a side to easily repeat the developed method over similar infrastructures, but still maintaining local structural peculiarities, which can influence pedestrian operations.
2.2. Real-world data collection
The step of real-world data collection consisted in shooting videos of undisturbed pedestrian movement. In order to hide the devices from people’s sight, four video cameras have been placed in strategic locations at the ends of the ramp, positioning them in order to have a whole view of the facility. Recordings have been taken in September 2018, month when the ramp is highly subjected to pedestrian flow. The recorded footages have been elaborated via a semi-automatic tool for pedestrian detection and tracking, which permits to detect situations of interest, i.e. near-misses, and to track each involved pedestrian. Trajectory data of the tracked users are in that way collected, as well as speeds and accelerations. To be able to gather useful and reliable data from video shootings, four tasks have to be followed: firstly camera calibration has to be run, creating a coordinate system, which will be referred to during the whole video elaboration. In this application, the absolute error values on map and camera views obtained via calibration equal respectively 12 cm and 4 pxl. The second passage is to identify the interesting events, by automatically saving shorter footages – 14 s overall: these shorter videos are the detections, on which the tracking step will be worked out. The tracking phase consists in characterizing each road user with a “shaped box” that has to be manually placed around the user at each selected frame-step in order to obtain its trajectory. As manual tracking is concluded, the trajectory can be smoothed to achieve a continuous one, and outputs can be provided: among them, two groups of magnitudes can be distinguished: behavioral magnitudes, provided via .csv files, and surrogate safety measures, which can be easily copied and pasted from the tool’s graphical user interface to Excel. To behavioral magnitudes belong the position, speed, acceleration (and other more specific values) at each frame of each tracked user; surrogate safety measures are indicators calculated rather for a chosen pair of interacting users.

2.3. Micro-simulation model set up
Generally, pedestrian microsimulation is used to study the dynamics of pedestrian flows on their main routes; often it is also utilized to pinpoint areas subjected to high crowds and to design alternative pedestrian itineraries. Specifically, pedestrian microsimulation aims at defining congestion points, criticalities, as well as at managing overcrowded places, planning and testing evacuation plans. In this research Viswalk has been used as pedestrian microsimulation software. This tool is based on Helbing & Molnar’s model [13] well known as Social Force Model (SFM). In this microscopic model each single individual is subjected to the resultant of instantaneous, external and internal, local forces, which rule the movement of the agent. The main idea supporting microsimulation and claimed by [14] is that pedestrians are used to walk in crowded locations and therefore they have subconsciously developed automatic strategies to avoid collisions with other people. These subconscious strategies can be simpler defined through behavioural rules built up on pedestrian’s final goal and on the conditions of the surroundings: to realize it, three components are considered, which together build the repulsive and attractive forces ruling pedestrian behaviour. These two forces merge then in a unique comprehensive strength, guiding the agent in its choices. The described model allows to make pedestrian simulated behaviour more realistic by calibrating its parameters and diversifying reactions in relation to age and gender of pedestrians, as well as to the discomfort felt by the individual while walking near other users. Among the SFM’s parameters which can be fine-tuned to better reproduce pedestrian dynamics there are:

- Tau: it is a relaxation time, i.e. the time within the pedestrian reaches its desired speed;
- ReactToN: number of pedestrians in the nearbies which influences the direction of the considered entity;
- ASoCIso (ASocMean) e BSoCIso (BSocMean): parameters ruling the social force between two agents, considering the force and the distance between them.
- Lambda: anisotropy factor. It defines the influence of objects on the individual, considering their position;
- VD: it is the impact that relative speeds have on the considered pedestrians. If VD > 0, velocities influence the force between two considered entities;
- Noise: stochastic force used to prevent deadlock situations in cases of indecision.
- In this research default values of the recalled parameters have been changed in the ones reported in Table 1, in order to better fit video information.

| Viswalk Parameters       | Default | Normal |
|--------------------------|---------|--------|
| tau (τ)                  | 0,40    | 0,06   |
| react_to_n parameter     | 8       | 4      |
| ASocIso                  | 2,72    | 1      |
| BSocIso                  | 0,20    | 0,10   |
| Lambda (λ)               | 0,176   | 0,176  |
| ASocMean                 | 0,40    | 0,40   |
| BSocMean                 | 2,80    | 2,80   |
| VD                       | 3       | 9      |
| Noise                    | 1,2     | 1,2    |
| PrefLato                 | nothing | nothing |

Pedestrian traffic analysis is normally based on the study of average values of speed, space and capacity, and it is strictly linked to Level of Service (LOS) estimation.

Here, pedestrian speeds and trajectories are used to evaluate the behaviour of the users in the considered area and to calculate surrogate safety indicators, like TTC and TAdv. Next paragraph briefly describes the method utilized to obtain SSMs directly from simulation outputs.

2.4. Surrogate safety measure calculation
While in the step of real-world data collection surrogate safety measures are semi-automatically calculated by the detection and tracking software, the microsimulation program does not automatically provide this kind of outputs. Therefore, two approaches have been initially thought: the first one implied the utilization of Surrogate Safety Assessment Model (later SSAM), a free-downloadable software developed by Federal Highway Administration – U.S. Department of Transportation (FHWA); the second approach was to directly calculate surrogate safety indicators. The first method has been soon abandoned, since both the reading of SSAM Manual and some experiments made with the software itself underlined the gap it has in managing pedestrian dynamics and safety. So, the direct calculation of SSMs has been addressed. To successfully develop this step, well known researches and definitions of surrogate safety indicators have been considered. [11], [15]. From the outputs of the set up simulation model, the calculation of relative speed, time to collision and time advantage has been carried out.
Figure 2. Definition of the magnitudes used for the calculation of SSM

Because of the specific conditions, it has been possible to consider conflicting pedestrians as moving points, each one characterized by its own position, time and speed, which meet in head-on collisions. These simplifications have allowed to calculate firstly the intersection time and location between the point pair. Defining with numbers 1 and 2, respectively the two pedestrians of the pair, the equations of their position at time $t$ are:

$$\begin{align*}
X_1 &= X'_1 + v_{x1}t \\
Y_1 &= Y'_1 + v_{y1}t \\
X_2 &= X'_2 + v_{x2}t \\
Y_2 &= Y'_2 + v_{y2}t
\end{align*}$$

(1)

(2)

where $X$ and $Y$ are the point coordinates, $X'$ and $Y'$ are the initial coordinates of each pedestrians, $v_x$ and $v_y$ represent the speed components and $t$ is the time (see figure 2). The conflict will happen when:

$$X_1 = X_2$$

(3)

And therefore when:

$$t^* = \frac{x_{1} - x_{2}}{v_x - v_y}$$

(4)

The conflict point will be the one defined by the $x,y$-coordinates at time $t = t^*$. According to [11], TTC coincides in the formulation with $t^*$, and thus for head on collisions it is:

$$TTC = \frac{x_{1} - x_{2}}{v_1 + v_2}$$

(5)

Where $X$ and $v$ are respectively vectors position and speed. To calculate Time Advantage, it is necessary to find the time differences between the two points passing the conflicting location. So it is:
\[ \Delta t = |t_1 - t_2| = \left| \frac{D_1}{v_1} - \frac{D_2}{v_2} \right| \]  

(6)

Where D are the distances at time t of the points from the collision location. Differently form [11], where the line ends – and therefore two points – are considered, here only 1 time difference is calculated, which determines also TAdv. Finally, speed difference between the 2 points is calculated to obtain relative speed:

\[ V_{rel} = |v_1 - v_2| \]  

(7)

3. Results and discussions

The research calculated on a side LOS information via a microsimulation software, on the other hand trajectories and surrogate safety indicators both from real world data and from simulation data. The aim was to understand safety level in a pedestrian confined space and to study the same configuration by microsimulation, linking it to surrogate safety parameters. Specifically relative speed, Time To Collision (TTC) and Time Advantage (TAdv) have been calculated from both source data. Starting from microsimulation results, the following outputs have been achieved (Table 2):

Table 2. Simulation geometry and results related to the monitored scenario: bidirectional flow - 1500ped/h on ramp areas named W1 and W2.

| ramp | Density | Perceived density | Speed (m/s) |
|------|---------|-------------------|-------------|
| W1   | 0.88    | 0.53              | 1.25        |
| W2   | 0.94    | 0.40              | 1.25        |

This values are strictly linked to Fruin’s definition of LOS, as it can be inferred from Table 3. Particularly, LOS has been obtained in terms of pedestrian speed (m/s) and density (ped/m²) – figure 3, and it stands within levels A - blue areas, and C - green zones. The light blue parts represent the evaluation start and end zones, which corresponds to the two ends of the considered ramp.

Table 3. LOS as defined by Fruin and used by Viswalk.

| LOS | Density (ped/m²) | Space (m²/ped) | Flow rate (ped/min/m) | Av.Speed (m/s) | Capacity v/c ratio |
|-----|------------------|----------------|-----------------------|----------------|-------------------|
| A   | <=0.27           | >=3.24         | <=23                  | <=1.3          | 0-0.3             |
| B   | 0.43-0.31        | 2.32-3.24      | 23-33                 | 1.27           | 0.3-0.4           |
| C   | 0.72-0.43        | 1.39-2.32      | 33-49                 | 1.22           | 0.4-0.6           |
| D   | 1.08-0.72        | 0.9-1.39       | 49-66                 | 1.14           | 0.6-0.8           |
| E   | 2.17-1.08        | 0.46-0.93      | 66-82                 | 0.76           | 0.8-1.0           |
| F   | >2.17            | <=0.46         | variable              | <=0.76         | variable          |
As regarding trajectories, from figure 4 it can be observed that the ones obtained through microsimulation are a little bit more homogeneous and distant the one to the other, spreading diagonally as comparing to the real ones, which develop longitudinally nearer to the axis of the ramp. Moreover, agents in the simulation video do not make stops and delays, and in this sense, there is an important difference between the two approaches.

Moreover, since velocities of the involved pedestrians are generally very similar, they provide little values of relative speed. To let the reader understand, the velocity mean value is 0.81 m/s for real world data and 0.13 m/s for the simulated ones. As a consequence, TTC magnitude increases. An interesting finding is TTC trend over time. As can be observed by figure 5, a sort of flipped bell graph has been obtained. Specifically, a decreasing trend is noticeable when pedestrians are approaching, the achievement of a minimum happens when they are developing the encounter, and finally, TTC increases when they are leaving the scene. While the first part totally agrees with the normal trend of TTC in vehicle-pedestrian encounters, the increasing branch doesn’t happen in that kind of near-misses, which tends to be normally flat. This is probably due to the difference in speed between the involved car and pedestrian: here, pedestrian speed difference remains quite constant, while their positions move away, letting TTC growing. This fact, even if not observable in other kinds of encounters, is supported by the theoretical trend of TTC, as let [10] notice. Also, both data achieved by simulation and real-world observation show some gaps in the calculation of relative speed and TTC. This is due to the vectorial definition of the parameters: relative speed is calculated as velocity difference between $v_1$ and $v_2$, which respectively define the first and second user speeds. So, in accordance with [15] $V_{rel} = || v_1 - v_2 ||$.

Then, if two trajectories are parallel, the value of relative speed will be null: data will show in this case a gap, and consequently TTC do it too.
Figure 5. Schema of the TTC trend over time, found from the simulation

Also the trend of Time Advantage over time showed an agreement between the two approaches. Specifically, both $T_{Adv}$ calculated from simulation outputs and the one obtained by video footages show an initial peak and a decrease with increasing time, as it can be inferred by figure 6.

Figure 6. Trend of Time Advantage over time in the simulation case.

Some observations can be made: first of all, in both cases very sparse data are noticeable and, $T_{Adv}$ peaks move over time in relation to the encounter features; as regarding simulation data, peaks are also visible in correspondence to the end of the trend; generally, these data have lower values than real-world ones, with peaks attesting around a value of 5s, while in real-world indicators, peaks achieve higher values, meanly around 9s.
4. Conclusions
The paper presents a 4-step procedure to calculate and compare surrogate safety measures obtained by using two different methods: real-world data achievement and microsimulation.

Real-world information has been obtained by video footages shot by cameras, set in order to cover the whole area of interest, and they have been elaborated via a semi-automatic detection and tracking software to achieve trajectories and surrogate safety parameters. A microsimulation model has been set up in Viswalk to simulate pedestrian movement on the chosen ramp and to additionally calculate its Level of Service: to guarantee the reliability of the developed model, all the major features of the infrastructure has been rebuilt and microsimulation parameters have been modified to better fit the observed conditions.

Surrogate safety measures have been automatically gathered by real-world video footages via a detection and tracking tool, which allows to pinpoint interesting events and to study users’ dynamics in a selected time gap. On the other side, since still no methods exist to automatically achieve surrogate safety indicators by microsimulation modelling, when dealing with pedestrians, they have been directly calculated starting from simulation outputs.

Several differences have been noticed between the two kinds of provided parameters: simulated trajectories are more distant and homogeneous then real ones, TTC trend shows a very good correspondence with its theoretical tendency, and TAdv has a correct variation over time, even if values are lower than real ones.

Overall, it can be observed that the calculation of SSMs by simulation outputs is surely a very useful step, but it needs regarding pedestrians still many improvements. The general well-fitting trends of the considered parameters give opportunity to improve their calculation, but certainly data filtering and better calibration techniques are needed.

References
[1] G. Scata, T. Campisi, M. Collotta and G. Pau, „A dynamic traffic light management system based on wireless sensor networks for the reduction of the red-light running phenomenon,“ Transport and Telecommunication, Izv. 15(1), pp. 1-11, 2014.
[2] J. M. Mayr, C. Eder, A. Berghold, J. Wernig, S. Khayati, A. Ruppert-Kohlmayr, „Causes and consequences of pedestrian injuries in children,“ European journal of pediatrics, Izv. 162(3), pp. 184-190, 2003.
[3] R. Elvik, A. B. Mysen „Incomplete accident reporting: meta-analysis of studies made in 13 countries,“ Transportation Research Record: Journal of the Transportation Research Board, (1665), pp. 133-140, 1999.
[4] J. Lee, M. Abdel-Aty and I. Shah, „Evaluation of surrogate measures for pedestrian trips at intersections and crash modeling,“ Accident Analysis & Prevention, 2018.
[5] A. Schadschneider, W. Klingsh, H. Klüpfel, T. Kretz, C. Rogsch and A. Seyfried, „Evacuation Dynamics: Empirical Results, Modeling and Applications,“ Springer, 2008.
[6] W. Daamen and S. Hoogendoorn, „Experimental Research of Pedestrian Walking Behaviour,“ v Transport Research Board Annual Meeting 2003 . Washington DC., 2003.
[7] M. Fitzpatrick, M. Brewer and S. Turner, „Another look at pedestrian walking speed,“ Vol. Journal of Transportation Research Board, 2006.
[8] Y. Tanaboriboon, S. S. Hwa and H. C. Chin, „Pedestrian characteristics study in Singapore,“ Journal of Transportation Engineering, pp. 229-235, 1986.
[9] T. Muralleetharan, G. Student, T. Adachi, T. Hagiwara, S. Kagaya, „Method to determine pedestrian level-of-service for crosswalks at urban intersection,“ Journal of Eastern Asia Society for Transportation Studies, Vol.6, pp. 127-136, 2005.

[10] A. Laureshyn, M. de Goede, N. Saunier and A. Fyhri, „Cross-comparison of three surrogate safety methods to diagnose cyclist safety problems at intersections in Norway“ Accident Analysis and Prevention, 2017.

[11] A. Laureshyn, A. Svensson, C. Hydén, „Evaluation of traffic safety, based on micro-level behavioural data: Theoretical framework and first implementation“ Accident Analysis and Prevention, 2010.

[12] E. Polders, W. Van Haperen, T. Brijs, „How to analyse accident causation: A handbook with focus on vulnerable road users“, Hasselt University, pp. 233, 2018, ISBN: 9789089130648.

[13] D. Helbing and P. Molnar, „Social force model for pedestrian dynamics“, Physical review E, Izv. 51(5), p. 4282, 1995.

[14] D. Helbing, P. Molnar, I. J. Farkas and K. Bolay, „Self-organizing pedestrian movement,“ Environment and planning B: planning and design, Izv. 28(3), pp. 361-383, 2001.

[15] L. Pu and R. Joshi, Surrogate Safety Assessment Model (SSAM) - Software User Manual, Georgetown Pike: U.S. Department of Transportation - Federal Highway Administration, 2008.