MODELING PEDESTRIANS´ MOVEMENT ON ROAD-CROSSING ENVIRONMENT

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ABSTRACT

In this paper, we address the problem of modelling the pedestrian road-crossing task, using multi-agent techniques. The model presented in this paper has been devised to provide a sound representation of the interaction between pedestrians and a more realistic approach for the interaction between pedestrians and vehicles. The model represents pedestrian's behaviour patterns at road crossing, regarding the decisions about where and when to start crossing the road. From this point of view, an attempt has been made to develop a model which considers both vehicular and pedestrian traffic. This paper identifies the impact of the step-by-step decision process of the pedestrians in the traffic flow of vehicles. Models with a non realistic step-by-step process, the pedestrians have a rouge impact on the traffic flow. Models with a well calibrated step-by-step process have the impact of pedestrians in the traffic flow is attenuated.

Keywords: Pedestrian, Crosswalk, Agent simulation

INTRODUCTION

Pedestrians are the most vulnerable users of the road system. The provision of adequate and safe circulation systems can reduce traffic accidents and reduce the discomfort due to the daily experience of risky situations.

An appropriate infrastructure for pedestrians and cyclists encourages the use of these modalities as an alternative to motorized transport. Improved conditions for getting around qualify the trips in which walking and cycling are complementary to motorized trips.

The design of projects concerned with pedestrian circulation should take into account the users' preferences and perceptions in order to improve the effectiveness of these structures (Sisiopiku and Akin 2003). A safe and pleasant road system basically involves five elements (Sarkar 2003): the physical separation of pedestrians and the motorized traffic; the control of pedestrians and vehicles flow; visibility; adequate communication through signalling, and help for pedestrians with special needs.

An appropriate design of pedestrian structures based on these elements may encourage walking without compromising the users' safety and convenience. Pedestrian safety and comfort may be affected by operational changes, as for example, in traffic signal timings. Pedestrian crossings are essential elements of the transportation system. Properly designed and located crossings perform two important functions: to create expectation among the drivers as to where the pedestrians might cross the road, and to encourage pedestrians to use the structures appropriately.

The emulation of pedestrians in traffic environment is a complex problem (Blue et al. 1997). Some authors use artificial life and cellular automata approach to model the rich complexity of the real movement of pedestrians, the interaction with each other, path planning, perception and avoidance of obstacle and physical constraints (Hamagami and Hirata 2003, Ronald and Sterling 2005). There are authors who combine the use of agent-based paradigm and cellular automata modelling techniques. Most of the research on pedestrian modeling are focused on crowd simulation and on pedestrian movement and interaction in urban environment (Shao and Terzopoulos 2007, Jian et al. 2005).

The simulation of pedestrian behavior and vehicle traffic has traditionally evolved separately and the association of these fields of research is difficult to find in the literature. Usually, traffic simulation models consider pedestrians as special vehicles, where pedestrians are represented by poor decision process and behavior models.

The interaction between vehicles and pedestrians has different levels of complexity. From a normal level of interaction, where pedestrians use sidewalks and cross the road only at traffic lights or crossing points and there is no longitudinal interaction, to a chaotic interaction, where is not possible to separate the flow of pedestrians and cars (Meschini and Gentile, 2009).

The model presented in this paper has been devised to provide a sound representation of the interaction between pedestrians and a more realistic approach for the interaction between pedestrian and vehicles.

The emulation of a more realistic pedestrian behavior pattern provides the basis for the identification of the influence of operational attributes, such as signal timing and project characteristics and the dynamics of the pedestrians´ road-crossing process as a whole.

Based on these considerations, this paper addresses the problem of modeling the pedestrian road-crossing task. The proposed model considers the behavior patterns at road crossings, considering the pedestrian's decision process about where and when to start crossing the road.

PROPOSED MODEL

The interaction of real pedestrians has influence on their walking behavior. Due to their characteristics, pedestrians can move around with more flexibility on a road environment than if using any other means of transport. Pedestrians have more flexibility to overcome obstacles. They need to avoid or overtake other pedestrians to maintain their speed, change directions, stop and wait. Generally speaking, they tend to keep a minimum distance from another pedestrian or obstacle.

In order to properly represent the natural complex pedestrian behaviour, the model was divided in three levels of simulation: macro, meso and micro. The macro level regards the initial and final location of the pedestrians, considering only the Euclidian distance between them. The meso level is responsible for the route generation. The micro simulation layer is concerned with space negotiation between pedestrians and the task of avoiding obstacles between them. The three simulation levels are described below.

Macro Simulation Level

The macro simulation level considers only the initial and final point of each pedestrian in simulation (Figure 2). Each pedestrian is created with an origin and a destination. Origins are defined by a point with coordinates X and Y. Destinations may be defined by points or areas. This information (initial and final points) is the input of the meso level.

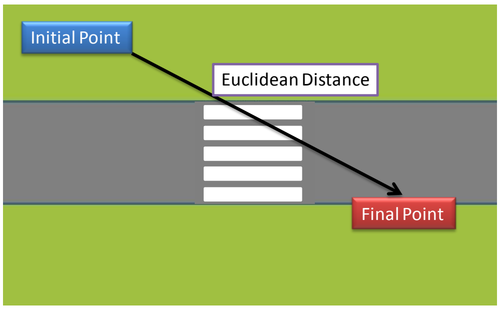

Figure 2: Macro Simulation

Meso Simulation Level

The meso simulation level is responsible for identifying the best route to reach the destination. This simulation level is defined by a layer of nodes that are connected to the neighbour nodes by two-way links. Each node of the graph represents a reference point of the simulation space. The graph layer contains only a partial number of the fine grid points (Figure 3). Using the graph layer, each pedestrian solves a route problem from the initial point to the final point supported by Dijkstra’s algorithm (Dijkstra, 1959).

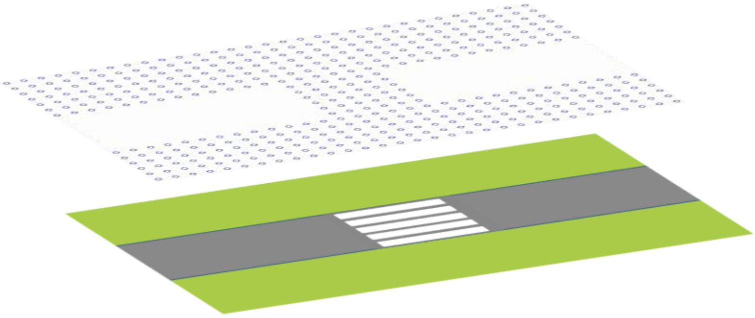

Figure 3: Micro Level Space and Meso Level Graph Layer

Micro Simulation

The micro simulation level considers the step-by-step pedestrians negotiation. Each pedestrian perceives the world and avoids the collision with obstacles and other pedestrians.

The pedestrian decides the best next step considering a combination of alternatives, defined by two parameters: a distance module and an angle step. For an angle step of 15 degrees and a distance module of 10 units, for instance, the pedestrian will evaluate 24 possible positions (10 units distant from the actual position) for the next step, regarding the meso simulation route, the final destination point, and other pedestrians.

Based on the Newtonian force models, the space negotiation between pedestrians is defined by a mathematical process inspired on the force field concept (Löhner, 2009).

Each pedestrian generates a power force around himself. The model calculates a resultant force for each point of the Cartesian space. This force highest value is aligned to the direction of the pedestrian´s velocity vector. The force is null in the opposite direction of the vector (Helbing and Molnar, 1998).

Each point of the space is influenced by the sum of the forces of all pedestrians around and the pedestrian uses that parameter to choose his direction.

Figure 4 shows a graphical representation of the force field generated by two pedestrians walking in opposite direction. The orange colour represents the intensity of the force field.

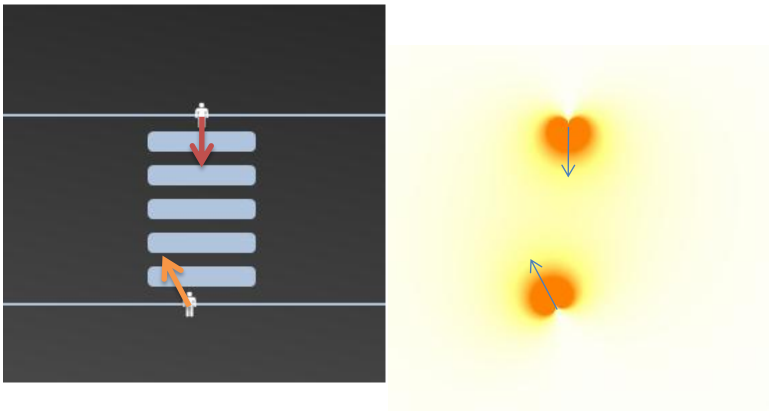

Figure 4 – Pedestrians' Force Field

To choose the next step the pedestrian verifies the intensity of the resultant force field $Ffr_{(x,y)}$, where it is composed by the resulted force $Fr_{(x,y)}$ and the distance from his objective point $d_{(x,y)}$ (eq. 1).

$$Ffr_{(x,y)} = Fr_{(x,y)}\beta + \gamma d_{(x,y)} \quad \text{(eq. 1)}$$

$Ffr_{(x,y)}$ represents the value of the resulted force field at any point x and y. The pedestrian evaluates 8 points to decide what is the best direction to choose. The pedestrian chooses the point with minimum value. β and γ are calibration coefficients that allow to regulate the influence of the force field or the distance on the choice of the next step. For instance, if the β is too high, the pedestrian will keep a relative high distance from other pedestrians. If the γ is too high, the pedestrian will try to choose the nearest point, it doesn't matter how close to other pedestrians it will be.

It is important to notice that terms like "force field" are used as nomenclature only, without a hard analogy with the physical concept.

$d_{(x,y)}$ is the Euclidian distance from the candidate's next step point to the final pedestrian's destination.

Assuming S as a vector defined as the speed of a pedestrian. To calculate the $Fr_{(x,y)}$ at a given point, two vectors are considered, S and a unit vector U at the direction of the point *x,y*. Figure 5 shows the $Fr_{(x,y)}$ calculation (Figure 5).

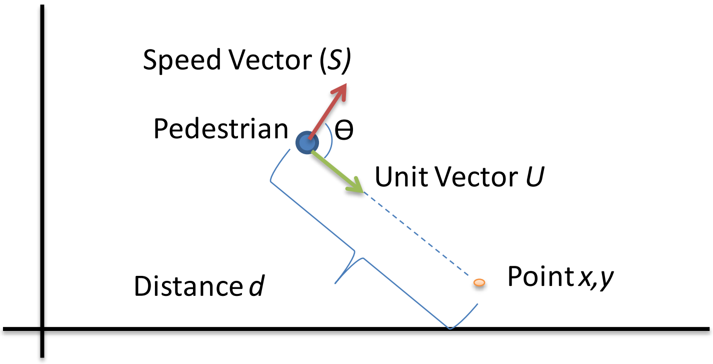

Figure 5 - $Fr_{(x,y)}$calculation

The intensity of the force Fr of a pedestrian pj is proportional to the coefficient α. The α coefficient is a function of the angle between the unit vector U and the speed vector S. It is inversely proportional to the square distance between the x and y point and the pedestrian's position (eq. 2).

$$\alpha_{pj} = 0{,}5 + \frac{\cos\theta}{2} \text{ (eq. 2)}$$

And θ is defined by eq. 3.

$$\theta = arc\ \cos\frac{S_{pj}.U_{pj}}{|S_{pj}||U_{pj}|} \text{ (eq. 3)}$$

The resultant force of one pedestrian is defined by eq. 4.

$$Frpj = \frac{|Spj|\alpha j}{d^2_{(pj,Frpj)}} \text{ (eq. 4)}$$

The resultant force Fr at any given point is described by the sum of the $Frpj$ come from each pedestrians present at the simulation, as follows (eq. 5):

$$Fr(x,y) = Frp_1 + Frp_{2+\dots} = \sum_{j=1}^{n} Fp_j \text{ (eq. 5)}$$

Therefore, the force Field intensity at any given coordinate (x,y) at the space will be the sum of pedestrians' forces.

Car and Pedestrian Interaction (micro simulation level)

A sound representation of the interaction between vehicles and pedestrians is crucial for a reliable evaluation of pedestrians crossing facilities. The formulation presented in this paper is based on a simple case that provides the basis for more complex structures. It has been developed as a first stage of a more complex modelling environment that should allow perception and reaction ability of both pedestrians and vehicles. It has been developed to prove the soundness of the pedestrian movement model subjected to the interaction with agents of other nature, as vehicles in crossing facilities. It can be applied to situations where pedestrians have crossing priority and only vehicles perceive and react to the presence of pedestrians. The model developed for this study assumes just one vehicle lane. A car following algorithm was modified to include the perception of the pedestrians by the vehicle.

The perception of the pedestrians by the vehicle occurs when a pedestrian overtakes an imaginary line parallel to the vehicle lane border, as shown in figure 6.

If a pedestrian overtakes such line, the vehicle evaluates the distance from the pedestrian and assumes a deceleration inversely proportional to this distance. If the distance is less than a minimal distance, the vehicle stops. In this case study, the model do not considers the possibility of a vehicle not stopping for a pedestrian. The imaginary line is sufficiently far away from the lane's border to prevent a vehicle to hit a pedestrian.

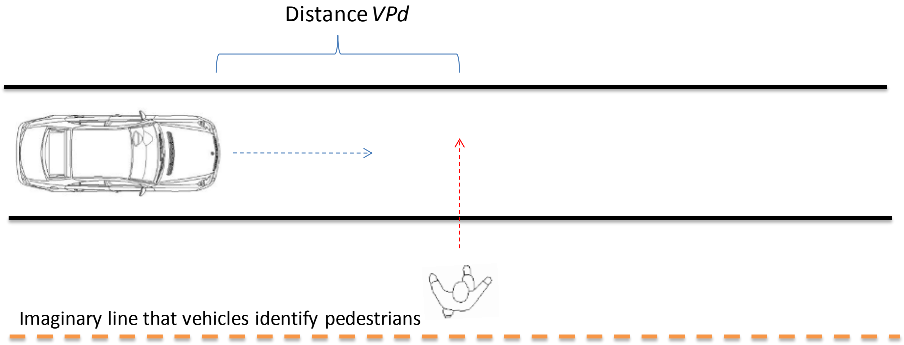

Figure 6 – Imaginary Line

COMPUTER SIMULATION

Lane formation

The model of pedestrian dynamics developed in section above has been simulated on a computer for a large number of interacting pedestrians in a corridor. With this simulation it is possible to identify the self-organization phenomena of lane formation (Helbing, 1995).

In this model application, blue and red pedestrians are generated in opposite sides and have opposite directions (Figure 7). Figure 8 demonstrates a simulation pattern where pedestrians movement are defined by a function with very low values of β (eq 1), In this situation, pedestrians movement decisions are mainly influenced by the search of the minimum distance to the destination, they have almost no influence of the force field, Under this circumstance, pedestrians are not able to solve the conflicts in the center of the corridor, and spend a long time to reach the destination. Figure 9 shows another simulation example, where β coefficient assumes a higher value in the pedestrian's movement process. As observed in figure 9, a self-organization phenomena occurs, and it is possible to identify the lane formation.

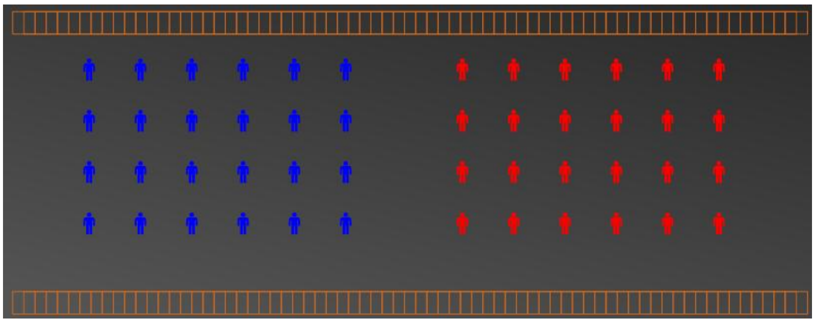

Figure 7 – Corridor simulation

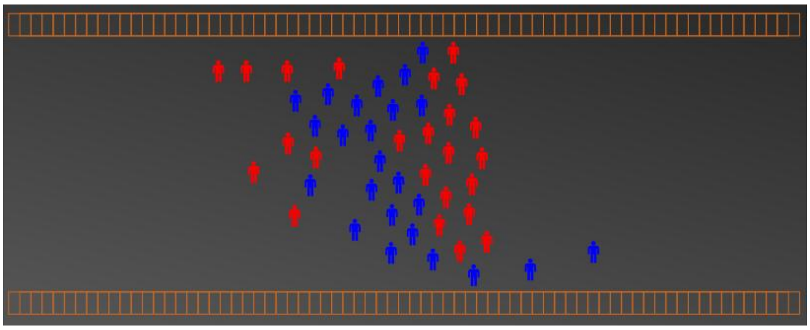

Figure 8 – Conflict in the middle of the corridor.

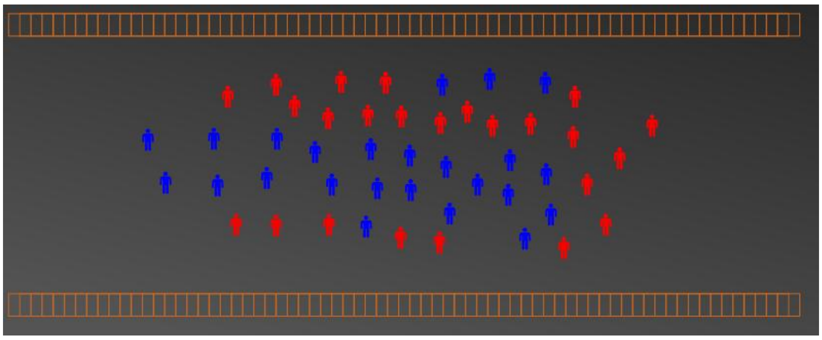

Figure 9 – Lane Formation

Vehicle and Pedestrian Interaction

Agent-based has been widely used in an efficient and effective way for studying granular traffic, but rarely considering the combined effect and interactions of pedestrians and vehicles in urban networks. Pedestrian traffic is simulated using simple behavioral rules combined with an agent-based approach. Different constraints affecting the mobility of the whole system are considered, which can be seen and even changed by the user in the simulated environment. The model belongs to the microscopic category where pedestrians/vehicles behave in their environment by making a sequence of decisions. The interactions among vehicles and pedestrians are also incorporated which signifies various effects, such as the generation of traffic jams.

With one-lane road, problems with traffic flow of vehicles can occur due to large traffic flows of pedestrians. Vehicles on the road, as a rule, give priority to pedestrians. For this reason, disturbances occur in the main vehicle flow (Liu and Seco, 2000) (Zhang and Duan, 2007).

The simulation considers a one lane road, and a crossing-area with priority to the pedestrians (Figure 10). Blue and red pedestrians are generated in opposite sides and have the intention to cross the road. During the simulation time, 20 vehicles cross the road with a headway uniformly distributed from 72 meters to 96 meters. The vehicle behavior is subject by a car following process inspired on (Gipps, 1981). The vehicle desire speed is 40 km/h, the typical acceleration is $3\ m/s^2$, the typical distance from vehicle to vehicle is 15 m. The desire speed of pedestrians is 1,3 m/s.

This simulation example was devised to identify the impact of the step-by-step decision process of the pedestrians in the vehicle traffic flow. A simplified, non realistic, pedestrian movement simulation process, led to a huge impact on the traffic flow. With a well calibrated step-by-step process, using the force field in the pedestrian’s next step decision, the impact of pedestrians in the traffic flow is attenuated.

Simulation tests were performed where the influence of the force field in the pedestrians step decision varied from 0% to almost 100%. In the scenarios where the influence of force field was near 0%, pedestrians blocked each other on the crossing-area, and therefore, blocked the traffic flow (Figure 10). The model configuration that led to the minimum delay to traffic flow was for force field equal to 25%.(Figure 11). Under these conditions, the decision about the pedestrians next step position is 25% based in the force field value and 75% based on the minimum destination distance. This calibration parameters allowed a lane pedestrian formation and the average time to cross the road was lower than the time observed with other parameters adjustments.

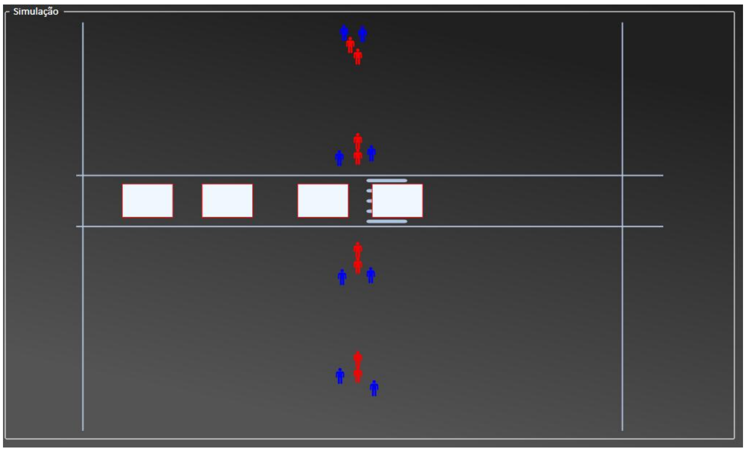

Figure 10 – No force field

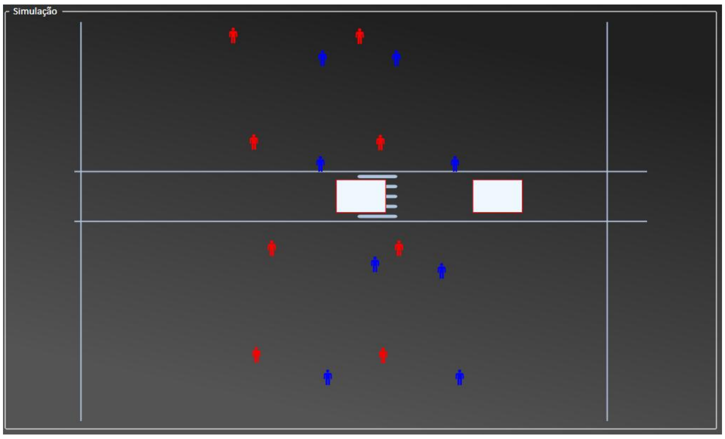

Figure 11 – Force field on 25%

Figure 12 shows a graphic that represents the average time of the 20 vehicles to transpose the simulation area. The 25% of force field influence has the minor average time: about 6 seconds.

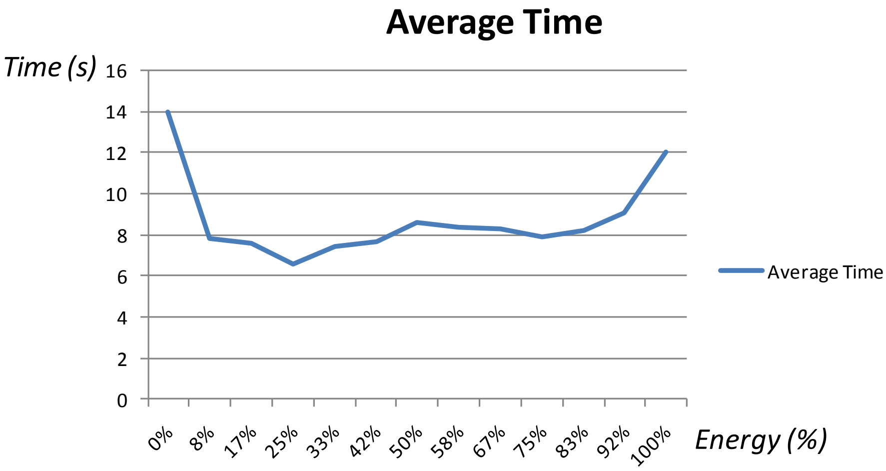

Figure 12 – Average Time

CONCLUSIONS

This study presented a conceptual model devised to improve the understanding of pedestrians' behavior pattern. The model was constructed by aggregating different approaches of pedestrians´ behavior. The modeling approach presented here provides a simple and reliable way of representing pedestrians´ behavior when crossing a road. The agent-based simulation approach provided the basis for representing the pedestrians according to their behaviours (Ashida, 2001).

Based on the preliminary results, some conclusions follow:

- The proposed classification of the simulation into macro, meso and micro levels provided an easier way to solve the route problem and pedestrians´ space negotiation process;
- The graph layer was able to solve the problem of pedestrians´ route;
- Force field concept is a simple and efficient way to incorporate characteristics of Social Force approach in the model (Helbing and Molnar, 1998);

In the future, to achieve a more realistic overall behaviour for the simulation, some aspects should be considered, such as:

- Include the perception of the vehicle to the pedestrians;
- Develop a heuristic to guide the crossing process of the pedestrian considering the type and the speed of the vehicle.

The conceptual model proposed in this study help the understanding of pedestrians´ crossings and could be used to quantify the provision of adequate systems for pedestrians can improve the use of these structures and, consequently, the safety of all users.

The incorporation of several theories and heuristics in a complementary way aggregates quality in the representation process of the pedestrians' behavior.

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