VIRTUAL PEDESTRIANS’ RISK MODELING

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ABSTRACT

All people move almost as pedestrians on the road network, but this activity is not as good as it should be. The loss of millions of lives and injury of others doesn't suffice architects, urban designers and policy makers to reconsider, radically, the design of the urban network, and to improve the use of priorities rules. In this paper, we present an exposition risk indicator for road accidents which can measure both pedestrians and vehicles risk exposition. For this purpose, we use our pedestrian’s dynamics fuzzy ant model based on artificial potential field [1], and for vehicles dynamics both IDM [2] and MOBIL [3] models. Simulation results for both pedestrians and vehicles traffic confirm predictions given by the first-order traffic flow theory. The current software solution will be integrated for pedestrians' accidents analysis in urban transportation networks.

Keywords: Virtual Pedestrian Model, Intelligent Agent, Simulation, Accident Risk, Transportation Theory.

I. INTRODUCTION

Each year millions people lose their lives on roads over the world. The majority of these victims are pedestrians hit by motor vehicles in various situations. These situations could be analyzed and classified in terms of the way pedestrians and/or vehicles behave and their relative settings on the road network. Pedestrians are exposed to accident risk either when standing or walking on the pavement or when crossing the road. The numbers of accidents depends on the local transport policy and the resources devoted to pedestrian safety. While the injury seriousness is a function of speed, the vehicles design, the road design and the vulnerability of the pedestrian, without taking into consideration those of the pedestrian's dynamics, since waling is not yet considered as an essential and necessary part of the overall transportation system.

Differences between the design of the planner and that of the user induce the dysfunction observed in the system failure caused by the high number of accidents. Assailly has reported that 70-
80% of deaths on the roads, between 15 and 59 years old are men [4]. However, according to Waylen and McKenna, the frequency and severity of accidents are higher among girls than boys. This observation can be explained based solely on risk exposure [5]. Indeed, observations show that there are gender differences in engagement in risk behaviour, as well as in the ability of risk assessment according to age groups (children, adolescents and adults) [6]. In addition to attitudes towards risk and their evaluation, any use of the road must also have a set of rules governing the interactions of the road environment [7]. The transgression of these rules causes dangerous behaviour that can lead to accidents. This act is even more among men than women for both drivers and pedestrians [8].

The road accident risk is used to be estimated as a rate of accident involvement per unit of time spent on the road network. Researchers are based on data collected by means of questionnaires or field observations [9]. In most cases, there is lack of information about the micro-environments met by pedestrians in those collected data, e.g. whether it concern a busy road or not, whether the crossings are made at junctions or mid-block locations, and so on. Hence only macroscopic risk indicators can be measured, which are heavily dependent on the often poor quality of accident data for pedestrians. Our aim is to develop a methodology for assessing the risk exposure of pedestrians in urban areas.

As non-crossing accidents generally represent a small proportion of pedestrian accidents [10], we assume that pedestrians are at risk only when crossing a road. We consider characteristics including traffic volume and speed without any distinction between different types of vehicles. Pedestrians may have different types of behaviour at crossings, by having many different routes in their trip, each one of these routes may entail different crossing types depending on their speeds. A trade is made between pedestrian's perception of the risk they are exposed to, and between speeds sequences, to let them finally choose an appropriate crossing behaviour, while taking into account the needed time for crossing and their desire to feel comfortable.

This paper is structured as follows. After a short introduction, section 2 presents pedestrian’s exposure concept. The third section presents some related works, while fourth one presents our fuzzy ant pedestrians model based on artificial potential fields. Later section five presents the measurements of pedestrians’ exposure to accident risk. Finally we describe obtained results given by chosen traffic light simulation scenarios for vehicles’ dynamics.

II. PEDESTRIAN EXPOSURE

It is important to understand the concept of pedestrian exposure and its relationship to pedestrian risk. There is no best measure of pedestrian exposure. However, according to the specific needs and objectives, some measures are better suited than others, such as the study of risk exposure between populations and its evolution over time.

When defining exposure, it is necessary to specify who is exposed and to which element. The term “exposure” originates from the field of epidemiology and is described as the situation when an agent is subject to potentially hazardous situation or substance. Exposure can also be considered as a trial event where a harmful outcome might occur. For example we are exposed to the possibility of getting injured by a vehicle each time we cross a street. Risk is a function of exposure and hazard. It refers to the occurrence probability of a hazardous event after a set of trials representing exposure units. In our purpose, exposure specifies the situation of the exposure to accident risk. Pedestrian exposure is therefore defined as a pedestrian’s rate of contact with potentially harmful vehicular traffic [11].
III. RELATED WORKS

In general, accident risk is represented by the probability of accident per unit time of exposure for a specific crossing section. Most of pedestrian’s causalities in road crashes happens along trips in urban areas, and specifically while road crossing. Many factors may contribute to collision or risk potentiality such as physical characteristics of the street and behavioral issues of both pedestrians and drivers. The consideration of these factors in the analysis of pedestrians risk exposure while crossing can produce a pedestrian-oriented planning of road design, traffic control and crossing facilities [12].

It is difficult to measure directly pedestrians’ exposure to accident risk, because it would involve tracking people’s movements at times. Several metrics are used in literature to measure pedestrian exposure in both micro and macro level, such as the product of pedestrian and vehicle volumes at an intersection and pedestrian distance traveled and pedestrian trips made but pedestrian volumes are the most frequently used. In situations where travel-based measures of exposure are not available, population-based measures are sometimes used for exposure approximation. The choice of exposure measure strongly impacts the resulting calculation of risk.

Pedestrians’ accidents risk is often examined in macroscopic level [13] by several indicators such as road collisions number in population of pedestrians [14-15], walking distance travelled [16] and spent time [17], trips number [18] or road crossings number [19]. Macroscopic indicators may be appropriate for a whole estimation of pedestrians’ exposure and for calculating aggregate risk indicators. However, they suffer from the lack of details and do not take into account the implications of the crossing behavior and the interaction between pedestrians and vehicles [20]. Comparing to macroscopic level, pedestrians exposure analysis in microscopic one have been given in only a few studies. The indicators developing in latter are based either on the number of pedestrians crossing a road section at given time intervals [21], or the product of vehicles and pedestrians number crossing a road section during time intervals[22].

Unlike macroscopic indicators, microscopic ones take into account pedestrians characteristics as well as traffic and road conditions. They may estimate more accurately pedestrians’ exposure at specific locations. Indeed, even if urban system offer to pedestrians many facilities, their crossing decision are made dynamically and spontaneously based on both their perceptions of vehicles gaps and aims to minimize walking distances and time. Therefore, the largest percentage of pedestrians road accidents occur outside specified crossing locations [23]. This crossing practice of pedestrians may affect the analysis of pedestrians risk exposure since a relatively unsafe crossing choice or an unexpected event may potentially increase it, and is not fully examined in existing research.

IV. FUZZY ANT PEDESTRIANS MODEL USING ARTIFICIAL POTENTIAL FIELDS

Our model is based on one of the most successful conceptual framework in swarm intelligence; which is Ant Colony Optimization paradigm. It is inspired by the pheromone trail laying and following behavior of ants. Such behaviors allow ant colonies to find shortest paths between their colonies and food sources. Ants communicate indirectly by the mine of chemical pheromone trails. The more ants visit shorter paths the higher the pheromone density remains for a longer time. However, the pheromone evaporates with time [1]. Like ants, pedestrians move in a two dimensional map, and use the same principle of creating trails, but in a virtual way.

Pedestrians are treated as particles moving on artificial potential fields having the form of a hill in which they're rolling toward their goals while being repulsed from obstacles. The goal point acts as an attractive force on the pedestrians and the known obstacles act as repulsive ones. The superposition of all forces has an impact on pedestrians' routes by guiding them toward the goal point while simultaneously avoiding obstacles.
In this model, the fuzzyfication of pedestrians' utility concerns only spatial perception (obstacles, preferred direction, amount of pheromone for dynamic floor, etc.). Our goal in this approach is to have a simple model integrating fuzzy modeling and the Ant Colony paradigm and artificial potential fields' concept. This model ensures an easy and effective navigation to pedestrians by attracting them automatically to their objectives while repulsing them from obstacles in their ways. Certainly, other cognitive and behavioral factors will be considered in our future work. This work is scheduled to consider dangerousness of crossing intersections by pedestrians. Perception of vehicle speed by pedestrians and other psychological factors can be integrated. The software architecture of the simulator allows this extension. For theoretical foundation, the fuzzy general utility proposed here, may be interpreted as a fuzzy probability, extending the crisp probability transition given by Ant Colony paradigm.

V. MEASUREMENT OF PEDESTRIANS EXPOSURE TO ACCIDENT RISK

1. Crossing roads: Risks and Skills

We assume that the pedestrians are exposed to risk when they cross the road. This assumption is almost realistic given the low accident rate out roads [10]. In addition, pedestrians crossing trajectories can have different shapes. The choice of trajectory is usually a compromise between the perception of risk by the pedestrian and his ability to cross with the most possible comfort. On the walkway, the path usually takes the form of a line perpendicular to the road. And out of it, when passing, pedestrians tend to cut corners and select oblique lines [24]. Regardless of the path and choose the section of road, pedestrians are trying to adjust their speed according to the situation they are exposed. The exposure for given entities is usually defined as the product of their speed and duration of exposure.

In a situation of crossing lanes, pedestrians must both perceive the elements provided by the mobile components of their environment (others pedestrians, motorists, motorcyclists, etc.) in a spatiotemporal volume. And secondly understand their meanings and be able to project their status in the near future. However, previous experience and knowledge can act as filters to select relevant information.
This crossing activity can be divided into some elementary steps (Fig. 5) starting from the selection of the place and time of crossing, after exploring the visual space and selecting relevant information to help estimating the potential impact time. And finishing by walking activity during which the pedestrians face the risk of accident. This decomposition process involves many prospective cognitive and walking processes, where pedestrians must use specific skills.

2. Case 1

An "exposure" may be defined as an event occurring at some location. Many monitoring instruments can generate "continuous" readings giving the concentration at a particular location at almost any instantaneous time. Thus the exposure of organism \(i\) located at position \((x, y, z)\) is given by:

\[
E_i(t) = \int_0^T c(x, y, z, t) dt 
\]  

(11)
In our context, pedestrians are exposed to accident risk in a road segment involved by a flow of vehicle during crossing time. Thus pedestrians' exposure to accidents risk is defined as:

\[ E(t) = \int_0^{t_c} q_v \, dt \]  

(12)

\[ E = q_v \cdot t_c \]  

(13)

Where \( q_v \) and \( t_c \) are respectively the vehicles flow and pedestrians crossing time.

We assume that the pedestrian cross a road having a given width \( D \) in a rectilinear line, with a given speed \( v_p = t_p \cdot D \).

Moreover, the vehicle flow can be expressed in terms of their densities and speeds, which they reach their maximum value if the density is null, and vanish in the case of maximum density (see Figure), according to the equation:

\[ \rho = \rho_{\text{max}} \left(1 - \frac{\rho}{\rho_{\text{max}}} \right) \]  

(14)

Therefore the pedestrians' exposure to accidents risk becomes

\[ \text{Exp}_{pV} = \rho_v \cdot v_{\text{max}} \left(1 - \frac{\rho}{\rho_{\text{max}}} \right) \cdot t_p \]

\[ = \rho_v \cdot v_{\text{max}} \cdot t_p - \frac{\rho_{\text{max}}}{\rho_{\text{max}}} \cdot t_p \]  

(15)

This exposure follows a parabolic curve. If vehicle density reaches its maximum value \( \rho_v = \rho_{\text{max}} \), accidents risk is vanished \( \text{Exp}_{pV} = 0 \) and pedestrians can cross inter vehicles. Also if the density of vehicles is zero \( \rho_v = 0 \), pedestrians are not at risk during their crossing, because of the absence of vehicles. So we have \( \text{Exp}_{pV} = 0 \). The problem arises for intermediate values of the density of vehicles within a center \( \rho_v = \frac{\rho_{\text{max}}}{2} \). These changes in the value of exposures to the risk of pedestrian accidents according to the density of vehicles are illustrated in the following Fig. 2.

Recently, the roads and intersections are being equipped with traffic lights, for pedestrians, which transition state depends on vehicles states. Pedestrians violate these crossing rules depending on their gender stereotypes. The most popular violation is passing traffic red light. When someone
managed to cross the gap between the two vehicles, others will speed up and follow him, imposing to vehicles to yield them the road. This leads us to believe that there is an accident risk for vehicles, this time imposed by pedestrians.

This exposure takes the same form as in the case of pedestrians:

$$\text{Exp}_{Vp} = q_p - t_v$$

Where $q_p$ and $t_v$ are respectively the pedestrians flow and necessary time for vehicles to pass a road section. This exposition also follows a parabolic curve. If the density of pedestrians reaches its maximum value $\rho_p = \rho_{\text{max}}$, the accidents risk of is zero for vehicles $\text{Exp}_{Vp} = 0$, as they must completely stop and wait for the passage of the pedestrians’ crowd. Whereas if the density of pedestrians is zero $\rho_p = 0$, the vehicles are not at risk during their passage $\text{Exp}_{Vp} = 0$, they can accomplish their travel in the absence of pedestrians.

The problem also arises for intermediate values of the pedestrians’ density within a center. This is the case where vehicles are being forced to brake to avoid a potential accident. This reaction is propagated to all the following vehicles on the road in question. These changes in the value of exposures to accidents risk for vehicles as a function of pedestrians' density are patterned the same way as in the case of pedestrians.

3. Case 2

The theory of traffic based on the study of trajectories. They allow determining the relevant traffic flow microscopic and macroscopic quantities. The trajectory $x_i(t)$ of vehicle $(i)$ describes the evolution of his position during the time $t$. This evolution is obtained by local inductive measures, either by loops or mean time, local quantities such as road traffic flow $q$, average speed $u$ and time headway $h_i$. The latter is calculated over a cross section $x$ by differentiating the passage time of two consecutive vehicles’ rear bumpers, which can be expressed by [25]:

$$h_i(x) = t_i(x) - t_{i-1}(x)$$

![Figure 9: Representations of headways variables](image)

Many parameters influence the headway, such as driver behavior, vehicle characteristics, and flow conditions. Its importance stems from the fact that it could determine the capacity of a road
Distance headways measure the distance between the rear bumpers of two consecutive vehicles at time instant $t$ as follow [25]:

$$s_i (t) = x_i (t) - x_{i-1} (t)$$  \hspace{1cm} (18)

One can note that both headways variables are correlated. In fact, if $v_{i-1}$ denotes the speed of the leading vehicle, we can obtain: $s_i \cdot v_{i-1} \cdot h_i$

Furthermore, the flow $q$ is a variable varying with time and location. It is generally defined by the average number of vehicles ($n$) that pass a cross-section during a unit of time ($T$). Hence:

$$q = \frac{n}{T} = \frac{1}{\frac{1}{h}} \sum_{i=1}^{n} h_i$$  \hspace{1cm} (19)

Thus the above formulation of pedestrians’ exposure to accidents risk could be written as:

$$E = q \cdot \tau_c = \frac{\tau_c}{h}$$  \hspace{1cm} (20)

VI. RESULTS AND DISCUSSION

The simulation tool is developed using Visual C++ IDE on windows operating systems. It has two components: an editor and a simulator. The first let the user to build its simulation map, either by putting road objects (road, lane obstacle, alert like uphill, and traffic light) for traffic road simulation. Or in the case of pedestrian’s traffic placing obstacles and generators. In both cases, user places statistics detectors and can modify simulation settings, before starting the simulation. The results are represented in real time for vehicles case and using ZedGraph graphical library for pedestrian’s case. At the start of simulation, the simulator manager control simulation by its two sub managers for both traffic systems: pedestrians and vehicles.

For vehicles simulation, we choose a traffic light scenario (Fig. 11). In this case vehicles must apply a deceleration to prepare to stop at traffic lights locations. And resume speed once the light turns green. We placed a detector”D0” before the traffic light to measure the flow of vehicles according to their densities. We placed a pedestrians’ generator at the top and a given goal at the bottom. As shown in figure 12, pedestrians are generated and cross the road section to achieve their common goal. The fundamental diagram obtained in real time simulation shows that vehicular traffic passes from one fluid to a congested regime.
The width of the road section occupies 6 cells each of which is of size 40cms. Moreover, the speed is similar to all pedestrians and is 1.4 ms⁻¹. One thus obtains that the crossing time for each pedestrian is 0.285s. We vary vehicles imposed speed on road cross section from 60km/h to 140km/h. One can note that all obtained diagrams follow theoretical variation of the pedestrians accidents risk indicator according to vehicles density or flow (Fig 8).
VII. CONCLUSION

In this paper, we present a measurement of virtual pedestrians and vehicles mutual accidents risk indicator. Pedestrians' dynamics are modeled using the basic fuzzy ant model [1], to which we have integrated artificial potential fields. Relation between density and velocity of pedestrian movement has so far mainly been analyzed using an empirical approach and fundamental relations found from the fitting of experimental measurements of the main quantities, while vehicles’ dynamics are modeled using Intelligent Driver Model for longitudinal travel, and the MOBIL model for lane changing. Simulation results confirm predictions given by the first-order traffic flow theory. Validation of the simulation model toward the real world data is recommended for further study. In our future work we plan to update developed simulation tools to complete accident risk indicator for both pedestrian and vehicles, to estimate the risk of crossing intersections.

VIII. REFERENCES


