INTERACTION BETWEEN PEDESTRIANS AND THEIR ENVIRONMENT WHEN ROAD-CROSSING: A BEHAVIOURAL APPROACH

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ABSTRACT

The significant number of injured pedestrians shows their vulnerability in front of vehicles. From the driver's point of view, pedestrians are slow, fragile, and with unexpected behaviour; their movements can abruptly change direction (sides, step backward). Moreover, their caution in the perception of the environment is sometimes limited.

After a brief state of the art in the simulation of the pedestrians including various connected problems, we will present a solution we have adopted and implemented within the behavioural traffic simulation model ARCHISIM. We will explain how our work is directly influenced by psychological findings related to human behaviour. Then we will give first results in term of impact of the infrastructure management on both pedestrian and vehicle flows, for concluding on future developments.

1. INTRODUCTION

Infrastructures dedicated to road traffic regularly evolves with the modifications of city needs, sometime taking into consideration sustainable development. The effectiveness and safety of infrastructures is thus continually put back to the study. Urban environment exposes by its complexity many constraints between on the one hand the level of safety, and on the other hand the performance of the network to maintain a sufficient flow capacity.

The significant number of injured pedestrians shows their vulnerability in front of vehicles. From the driver's point of view, pedestrians are slow, fragile, and with unexpected behaviour; their movements can abruptly change direction (sides, step backward). Moreover, their caution in the perception of the environment is sometimes limited.

It should be added that pedestrians and vehicles are completely antagonist in their movements, considering that their trajectories generally cross themselves in straight angle, which is the worst possible interaction. This confrontation can however be minimised by infrastructure equipment (protected passages, traffic lights), or even avoided (elevated passages). Each one
of those elements has impacts on the pedestrian's safety, but sometimes at the detriment of traffic flow capacity. Furthermore, it is difficult to design equipment which has full efficiency and safety. For example, elevated passages give a full safety for the movements of pedestrians, but the effort to climb and descend makes them sometimes not very attractive.

Conducting experiments in actual situations are often expensive, and sometimes impossible for safety reasons. Simulation is thus required, as a decision-making tool for the evaluation of the various solutions, from the point of view, at least, of both pedestrians and other road users. The task is particularly delicate for complex situations such as in urban environment, where many kinds of users interact, particularly, at the points of the roadway where vehicle flow and pedestrian flow intersect. To conduct such studies 1- current traffic simulation are limited, as they don’t have relevant model of interaction between vehicles and pedestrians (they mainly don’t care about pedestrians) 2- current pedestrian simulation models are inadequate because they include poor simulation of vehicular traffic.

Our objective is to model the interaction between the pedestrian and the vehicles, focusing on pedestrian behaviour when crossing the roadway, and so to improve the validity domain of our ARCHISIM traffic simulation software. Our aim is to design a new kind of tool, allowing to study the impact of infrastructure equipment on the traffic capacity and safety, from both vehicle and pedestrian point of view.

After a brief state of the art in the simulation of the pedestrians including various connected problems, we will present the solution we have adopted, directly influenced by funding in the psychology of behaviour. We will then give our first results, for concluding on future developments.

2. State of the art in the simulation of the pedestrians

There is few references on simulations of pedestrians in the task of crossing the road [Juhász, 1997], [Wan, 2004]. But when we widen the subject to general simulations of pedestrians, we find many connected research studies such as

1. congestion at the entry or exit of a room ("bottleneck"),
2. pedestrian counter flow ("bi-directional flows"),
3. movement in closed corridor,
4. itinerary choice (the "Traveling Salesman Problem").

The first ones gather in a part "simulation of crowd", while the last ones are more "cognitive". In our study, we are interested in roadway crossing, but the techniques implemented in the other disciplines can possibly be useful; we will thus develop them.

There are numerous algorithms to simulate a crowd of pedestrians, resulting from widely varied domains such as physics, biology, mathematics, and even from traffic theory. On the other hand for a more evolved pedestrian behaviour there are only some methods inspired by psychology models.

2.1 Crowd problems: the gas theory

In physics, gas is modelled according to several theories, "lattice gas models", and some of them were taken up by pedestrian flow modelling in narrow passages. The use of three models
is described in [Isobe, 2004]: "lattice-gas model" for the random walkers, "molecular dynamic model" for the dynamic walkers, and an intermediary "mean-field rate-equation model".

A control experiment is recorded in an actual corridor about twelve meters long and two meters wide, where two opposite passenger flows cross. Several simulations are then carried out using the models above. Probabilities to go straight, on the left, on the right or even to move back are defined according to the occupation of these locations, according to simple laws such as \( p(\text{go to left}) = Dm + (1-Dm)/3 \) where \( Dm \) is the power of the bias in relation to the central axis.

As results, they obtain densities and arrival times almost identical to experimental results (i.e. converging according to simulations).

This kind of modelling is thus validated from a "macroscopic" point of view, but does not offer proof that the effective behaviour matches the one of real pedestrians.

2.2 Use of the force field theory

In this kind of method, movement is seen as a vector, resulting from the minimisation of a cost that the environment imposes on the direction. Some cost factors are detailed in [Hoogendoorn, 2004]; the "drifting cost" which indicates velocity (or reactivity) of the pedestrian in his deviation from his initial trajectory, the "proximity cost" caused by the presence of other pedestrians in his walking area, and the "acceleration cost". The cost of proximity, which is the most significant one, is defined as the sum of the distance between each pedestrian, raised to an exponent.

The model of force fields is not enough in itself to develop a complete pedestrian behaviour, but in a small area it allows simulating “realistic” reactions with the close environment.

2.3 Cellular automata

We will take [Burstedde, 2001] as an example. The environment is discretised in checkerboard, where each pedestrian is held in a cell. The authors imagine (without doing it) a finer checkerboard, where one pedestrian would take the space of four cell (or even more). Each particle has a 3x3 matrix of preference, describing the probability for this particle to move in each neighbouring cell. In case of conflict between two particles, only one remains at his place and the other one moves, the choice between each is done according to the probability of each one to go on this cell. The model is applied for simulating a bottleneck situation; results are given in terms of evacuation time.

This model is a kind of simplification of more complex theories such as those above, with the same kind of results, the same advantages (simulation of close conflict situations) and the same disadvantages ( individual pedestrian behaviour sometimes far from actual ones).

2.4 Macroscopic studies

The traffic theory is well developed for vehicle flow. The "macroscopic" modelling, in traffic engineering terms, corresponds to the study of "global" parameters of the vehicles flow such as the density, the capacity, and the mean velocity. Use of such models appears for pedestrians only in specific cases such as "stream following", similar to "flood" of pedestrians.
Let's thus quote [Hoogendoorn, 2004b], who gives a formula for the capacity of a bottleneck, according to its width and the passengers density. Another study, [Lam, 2003] gives a formula for the speed of pedestrians' flow in a closed corridor following a commercial zone.

These studies can be used for validating a model from a macroscopic point of view. Moreover, the studied environment has only one parameter (the pedestrians file), even in the bi-directional cases.

**2.5 Behavioural models; list of tasks**

They are models directly inspired by psychological findings. Most of them split the pedestrian movement into successive steps. The type of proposed algorithm is thus procedural, with symbolic parameters (gap timing, safety factor...).

For example, in [Wan, 2004], the gap acceptance (i.e. the period that a pedestrian accepts before a vehicle cross his way), is controlled in this manner (CG stands for the size of the critical gap for pedestrian crossing):

1. Vehicle Arrival
2. Assign next inter-arrival time as $i$
3. If $i$ is larger than pedestrian critical gap CG then 5. else 4.
4. Assign indication variable for crossing street as 0, goto 8.
5. Assign indicator variable for crossing street as 1
6. Keep variable value as 2 for duration $i$-CG
7. Assign indication variable for crossing street as 0
8. Keep variable value as 0 for duration CG

This algorithm is included in a more global model of the crossing process, which is itself an lower-level model of walking while crossing a road.

This kind of model is the basis of a structured pedestrian implementation, in such a complex task as road crossing. However it defines only a framework; when the steps are defined and detailed, new criteria cannot be ignored (calculation of variables, management of local conflicts...).

Let's quote also the algorithm described in [Juhász, 1997]. It returns the decision to cross or not cross the roadway, according to the presence and the speed of a vehicle. It is limited; deals only with straight lines, and doesn’t manage interactions within pedestrians.

**2.6 Synthesis**

Two kind of problems have been distinguished, the crowd and the road crossing. The first one uses algorithms which are mainly reactive, and the second is procedural. Most of studied articles involve one of them, and propose adequate solution; however one cannot forgive the opposed aspect, and often implementations uses a balanced mixture of the known methods.

The validation is an often encountered difficulty in the literature. For crowd simulations, most of validations are comparison in macroscopic terms with a real experiment, and don't say anything on the actual noted behaviour, only [Osaragi, 2004] has one. The procedural algorithms don't seem to be validated, or only in macroscopic terms too. It would be necessary to find a method of validation for a behavioural algorithm.
To conclude, all of the proposed algorithms used fixed parameters, nevertheless sometimes several simulations are launched with slightly different parameters with an aim of tuning the similarity with the live experiment. But what can one deduce from these formulas for slightly different situations? In [Isobe, 2004] the authors changed the dimensions of their corridor, and their simulation diverged as much from the experimentation. Could one have an algorithm which adapt according to the situation?

3. Behaviour

We must clarify what we understand by "behaviour", and how to approach it.

Basically, the behaviour is defined by the simple following definition: "the set of the actor's reactions in front of what it detects of his environment". This includes the actions led on the environment (immediate actions and long term actions), but also the changes in its internal state (his "thought"), if himself is modelled.

In regards to the vehicle driver, several psychologists have carried out in-depth studies. According to [Michon, 1985], the behaviour is divided into three levels (figure 1);

The strategical level that defines the general planning stage of a trip, the tactical level corresponding to maneuver control, allowing them to negotiate the directly prevailing circumstances, and the control level with automatic low-level actions.

![figure 1: Hierarchical view of driver behaviour](image)

A pedestrian is fairly different from a vehicle driver, but driving task, particularly in its cognitive dimension, have been studied in-depth for a long time [Saad, 1999] and we think it can be relevant to use parts of psychological findings related to driving task for pedestrians (particularly those which propose a generic model). Of course, we have to adapt these findings to take into account the particularities of the pedestrian.

For a pedestrian, the environment is constituted of
1. an infrastructure (pavement, roadway, median) with its equipment (road-marking, raised passage, traffic lights), immovable obstacles (walls, trees, posts, parked vehicles),

2. other infrastructure users: other pedestrians (going in the same direction, in the opposite one, or crossing his path), vehicles (which mainly cross his path)....

The goal of a pedestrian is to reach his destination, following an itinerary. At each fraction of time, his movement amounts to a displacement (speed), in a direction (course).

The way a pedestrian behaves differs from the way a driver behaves for many reasons; one can distinguish at least:

1. Despite of its elevated position, the perception that the pedestrian has of his environment is sometime less complete than the vehicle driver's one; this is mainly due to the more selective concentration of almost pedestrians, and also to a reduced vision of some others (particularly children).

2. The vulnerability of the pedestrian against vehicles can cause widening of the safety margins, and to lengthening of the itinerary for aim of safety.

3. The movements of pedestrians can take any direction, and are limited in speed. Moreover these two parameters (direction and speed) can change abruptly.

Of course, and as for drivers, but perhaps with more heterogeneity, behaviours vary considerably from one pedestrian to another, according to his age, his state, his destination....

To match the hierarchical view of Michon in the case of a pedestrian, the strategic level would correspond to the planning of the itinerary: according to global information on the environment (infrastructure, other actors), the pedestrian mentally traces a going way from his origin to his destination (at any moment he can modify this itinerary). Then comes the tactical level: the pedestrian avoids nearest obstacles and adapt its behaviour to local surrounding. At the operational level, he moves (speed/direction pair) which answers to the deviation decided by the tactical level. In this study, we focus on the tactical level.

4. Presentation of ARCHISIM

A simulation of pedestrians with a psychological approach needs a model which already uses a multi-actor basis in the modelling of the pedestrian environment. That is why we use ARCHISIM, already recognized for results in the modelling of vehicles [Esplié, 1999].

For more than ten years the INRETS (French National Institute for Research in Transportation and Safety) has conducted research on behavioural microscopic road traffic simulation based on actual driver behaviour. The driver model results from studies of driving psychology [Saad, 1999], that have been implemented following a multi-actor point of view [Esplié, 1999]. The main objective of ARCHISIM traffic model is to simulate traffic and to study the way in which traffic phenomena occur (figure 2). The postulate is that traffic comes from individual actions and interactions of various actors. This novel way of simulating traffic has now been validated for motorway situations, current works are focussing on urban situations.

A powerful feature of ARCHISIM is the opportunity to integrate various modules such as a scenario module, a 3D-imaging module (figure 3), a data recorder module, etc.
5. Our Pedestrians Model

Because of the structured way the infrastructure elements are designed for vehicular traffic, the tactical level for a driver mainly means to determine the obstacles on its lane and on neighbouring lanes, in terms of the other vehicles' speed, then to choose the less constrained lane [Sameh, 1999]. Both short term and medium term situations are taken into account.

Infrastructure dedicated to pedestrians is not so structured. The pedestrian has no predefined lanes, but one can consider that the itinerary of a pedestrian defines a road. The obstacles on his road still force him to deviate from his trajectory to avoid them. One can then consider that the pedestrian draws virtual lanes around his itinerary (road) and, same as drivers, follows the less constrained lane.

5.1 How to block a lane

For a given vehicle, all other vehicles are on the same reference of lane as him; even when crossing, the lanes of the cross depend on the continuity of the current road lanes. Each other vehicle thus blocks the lane where it is (at this moment), and the degree of bother corresponds to a difference in speed with the studied vehicle. For a pedestrian, the other pedestrians (and vehicles) can cut his trajectory in any direction.

In the figure 4, the pedestrian A is obstructed by the pedestrian B; it means that if none of both change speed nor direction, then they will meet at the point C. To avoid it, pedestrian A should shift towards the left or the right side, to pass respectively in front of or behind the pedestrian B. In the figure 5, pedestrian A will be in position C when the pedestrian B arrives at his level; B will be in D when A passes in front of him. Thus pedestrian A has nothing to do, but if another pedestrian force him to deviate towards his way, he may meet the pedestrian B at point D. So, as the figure 6 shows it, pedestrian A has to move through a whole of ways blocked at various places.
Figures 4, 5, 6: Ways of pedestrians

The points C and D (as given on figure 5) are calculated simply by geometry, in the following way.

Definitions:

1. A and B: the points where are respectively situated the pedestrians
2. A2 and B2: some points in their respective trajectory (that is just in front of them)
3. vA and vB: their immediate speed
4. ex: boolean returned with C and D, his value is TRUE if these points really exist

Algorithm:

1. IF vA is almost zero THEN ex <- FALSE, END of the function.
2. IF vB is almost zero THEN D <- B ELSE:
3. Ap <- a point such as the straight line (A,A2) is perpendicular to (A,Ap)
4. Bp <- a point such as the straight line (B,B2) is perpendicular to (B,Bp)
5. E <- intersection between (A,Ap) and (B,Bp)
6. IF E doesn't exist THEN
7. the pedestrians walk in parallel, simple calculation of C and D,
8. END of the function.
9. IF E and B are the same point THEN
10. C <- A, D <- B, ex <- TRUE,
11. END of the function.
12. Bp2 <- a point such as (B,B2) is perpendicular to (B2,Bp2)
13. E2 <- intersection between (A,Ap) and (B2,Bp2)
14. alpha <- the angle (B,E,E2)
15. n <- vA/vB
16. beta <- arctan( (n*sin(alpha)) / (n*cos(alpha)+1) )
17. F <- rotation of B, of origin E and of angle beta
18. D <- intersection between (B,B2) and (E,F)
19. C <- orthogonal project of D on (A,A2)
20. IF A between A2 and C, or B between B2 and D,
21. THEN ex <- FALSE (C or D falls "behind" its respective pedestrian)
22. ELSE ex <- TRUE
23. END of the function.

5.2 Thickness

A pedestrian can't be summarised to a point, as we calculated above, for two reasons. The first one is the width of the pedestrians and the vehicles; indeed if one foresees a weak space between two obstacles, one is likely not to be able to actually pass. This space is shown in figure 7. However, it is not significant to take that in account because it is enough to add a fixed width around each point to approximate the space of conflict correctly. The second reason is much more significant; the security margin.
5.3 Security margin

It is a matter of perception by the pedestrian of the time to collision. A pedestrian never calculates arctangents when he crosses the roadway, he has only an idea on the project to walk in front of or behind such or such obstacle. When a car arrives at far, he can't envisage to pass immediately in front of it. There is thus a safety margin to calculate around the obstacle, especially when it is about a vehicle. To know dimensions of this zone, we must request the psychologists' works.

There are many studies dedicated to the perception of the TTC ("time to contact") by various types of users. According to [Simpson, 2003], the minimal time for the vehicle to reach the pedestrian walkway, at which the pedestrian lets it pass (called "rejected gap") is about six seconds (their results are from 4.50 to 7.22 according to categories). In urban environment, with a speed of 50 km/h, that corresponds to a walk of safety of 80 meters, as illustrated in the figure 8. Thus, very often, the appearance of a vehicle is likely to block all the lanes of the pedestrian.

5.4 The decision

With the data resulting from previous calculations, we can determine which lanes are blocked, and at which location. In our algorithm, we consider only the first location blocked for each
way, and the nature of the obstacle. The lanes correspond to a discretization of the environment, to allow simplified management. Then we carry out the following lines:

1. Among the free lanes, move towards nearest. If there are none:
2. Among the lanes blocked by pedestrians, move towards most tardily blocked. If there are none:
3. It means that all lanes are occupied by fixed obstacles or vehicles. Slow down the speed, compute again the blocked lanes, and restart at first step.

This procedure is executed each step of time; the virtual laneways are thus reconsidered according their state at a particular time.

6. Preliminary results

We implemented such an algorithm in the ARCHISIM model, and we obtained a behaviour such as the sequence of the figure 9. This example shows only pedestrians, that cross a walkway (the rectangle), so their itineraries are initially straight.

![Figure 9: Movement of pedestrians](image)

The pedestrians avoid themselves while following there itineraries (which is not a straight line). We focus on two pedestrians, A and B, whose destination are marked (x). Pedestrian A finds a hole in the flow of the antagonistic pedestrians, the pedestrian B on the other hand chooses to by-pass the pedestrians in front of him.

Pedestrians and vehicles interact. Pedestrians halt, slow down or deviate from their trajectory. Vehicles slow down when pedestrians block their lanes. In case of large traffic jam, pedestrians halt, otherwise they adapt their behaviour to the situation.

We are currently empirically refining our model and we will shortly start the validation phase. We will first validate it at a microscopic level, by comparing the behaviour of our simulated pedestrians with those of actual one's (trajectory deviation). Then, we will validate it at a macroscopic level by assessing the pedestrian flow parameters (average values of density and speed). This validation is for us compulsory; as we have to assess that the emerging flows, coming from behaviours and interactions at individual level, fulfil actual traffic flow parameters.
7. **Conclusion: limits and perspective**

We design a simulation of pedestrians that borrows from similar work on drivers, and also from work of psychologists about pedestrians. Preliminary results show close conformity with reality.

We however noted some limits with this step:

1. In some cases of parallel or symmetrical trajectories, the small margin of error from the waste of time in deviation may cause an underestimation of the embarrassment of the other pedestrian.
2. If two pedestrians have almost the same trajectory, we notice that the one behind makes an oscillation in the will to pass on the left or on the right. To avoid this instability, it would be preferable to widen the obstacle map by considering the next time step, according to each choice.
3. We based the algorithm on the assumption that the pedestrians always move right in front of them. That is true in a single time step (very short), but we could anticipate curved trajectories, if we know them in the intentions of the other pedestrians.
4. The algorithm doesn't work in a case of "catching up" (a pedestrian behind another slower, that he will obstruct after catch him up). Conceptually this is reasonable; we can consider that one does not take into account the people behind oneself. If not, it is necessary to add a second formula to the algorithm.

As perspective, in addition to handling the limited cases, we intend to individualize the pedestrians, taking into account their individual characteristics (for example on the rejected gap) for better heterogeneity of this population.

**References**


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