MICROSCOPIC PEDESTRIAN SIMULATION CONSIDERING HETEROGENEITY

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ABSTRACT

Living in a dense populated area as Tokyo, Japan, makes it necessary to integrate pedestrian movements into planning and operation decisions. Limited space and fear of stampedes during evacuations determine now construction plan boundaries. While work so far has neglected the heterogeneity of crowds, this paper investigates and models different pedestrian types crossing a high density intersection in downtown Tokyo, Japan. Based on a 24 hour video observation, parameters for different user groups have been extracted and used in a microscopic simulation model. Additionally, this paper offers a conceptual model for group movements in a crowd. Since not enough data could be collected, the validation of the model remains for future work.

Keywords: pedestrian, microscopic, heterogeneity, simulation

INTRODUCTION

Simulating pedestrians has become an important field of transportation research. Knowing how pedestrians facilitate common areas in cities, how clients move through shopping malls, airports or train stations and more and more importantly, how do they behave in the scenario of an evacuation. Many walking experiments have been performed to determine the necessary parameters for pedestrian simulation and several models for different usage have been developed. In existing models, heterogeneity of pedestrians is not included, or rather limited to their size, speed variation or a general factor. Considering the limitations of observing pedestrians this seemed satisfactory. However, users of such models are getting more demanding and pressure on construction companies and architects, to design areas

and facilities for maximum profit and safety, we think it is necessary to have another look into the effects of heterogeneity to pedestrian flows.
In Tokyo, Japan, the density of pedestrians inside the city is very dense and high-rise buildings allow plenty of opportunities to observe pedestrian flows over a long period of time. For this paper we chose a high definition video footage from a 24 hour observation of one of Tokyo's most busiest pedestrian crossing close to Shibuya station in downtown Tokyo, where high volumes of pedestrians are crossing in different angles while vehicle traffic is halted completely. We have divided the crowed into pedestrian classes:

I. Office workers (usually in a hurry in Japan)
II. Persons with a pram or tourists carrying a suitcase
III. Couples & Family (small group walking closely)
IV. Others (everyone else)

For these groups we have analysed individual speeds, occupied space, and the changes in walking directions to formulate a microscopic pedestrian model considering the heterogeneity of the crowd. For groups, we have developed a theory to simulate the patterns in which they break up and unite during the walking process when reaching an obstacle.
In the following we will give a brief review on pedestrian simulation before describing our model as extension of an existing pedestrian model by Asano (2009). Afterwards we introduce our calibration data-set and compare it with our simulation results.

PEDESTRIAN MODELLING

There are several general forms of microscopic pedestrian simulation. Gipps and Marksjo proposed in the benefit cost cellular model in 1985. In their model each cell can contain up to one pedestrian and has a score which indicates the attraction of the cell and the pedestrians move towards the maximum benefit. Other cellular automata approaches have been followed by Schadschneider (2002) Adler, Blue (2000) and Burstedde et al. (2001). Okazaki (1979 - 1993) has deployed a magnetic force model for pedestrian movement. Each pedestrian and obstacle has a positive pole while the destination has a negative pole. By applying equations of motion in the magnetic field, pedestrians are moving towards the destination, avoiding obstacles and other pedestrians. Helbing (1991 - 1999) developed the social force model in conjunction with Molnar and Vicsek which has similarities with both the magnetic force and benefit cost cellular models. Each pedestrian is driven by social forces that motivate the pedestrian. The sum of all forces creates the movement. Agent-based simulations, bases the simulated pedestrian on the paradigm of an agent as an entity that acts and interacts autonomously. Although, in principle, it is possible to integrate complex details of higher-level cognitive abilities, most proposals for agent-based pedestrian simulations only deal with collision- free, goal-oriented movement. Examples for the latter are Osaragi (2004), Willis et al. (2000), Teknomo (2002), and Dijkstra et al. (2006). For a detailed overview in relation to public transport facilities, see Daamen (2004). Last in this list is the application of econometric modelling to pedestrian movement dynamics. Bierlaire et al. (2003) suggest a statistical model that uses movement directions and speed to model pedestrian dynamics based on automatic video surveillance data. Video data from experiments and observations is also used by Hoogendoorn, Daamen and Bovy (2003). Notable enhancements have been conducted by Meguro (2004) and Asano (2009).

MODELLING SINGLE BEHAVIOUR

Based on the model of Asano (2009) we have performed some adaptations to use it for pedestrian simulation at intersections. First we have extended the model to a multi-class model, since the original has just one single type of pedestrians, and secondly we made some adjustments as described in the following.

Determination of surrounding obstacles and pedestrians

To evaluate the surroundings each pedestrian has a scanning area, in which all obstacles, may they be other pedestrians or structures (walls, edges, …), are detected. Based on a pre-defined, pedestrian type specific angle, and the maximum speed this area is bounded as shown in Figure 1. For obvious reasons, the pedestrian is not taking into account what happens behind him, even though one could argue that noise is triggering pedestrian behaviour as much as visual perception. But since we have no acoustic trigger in the model we can ignore this effect.

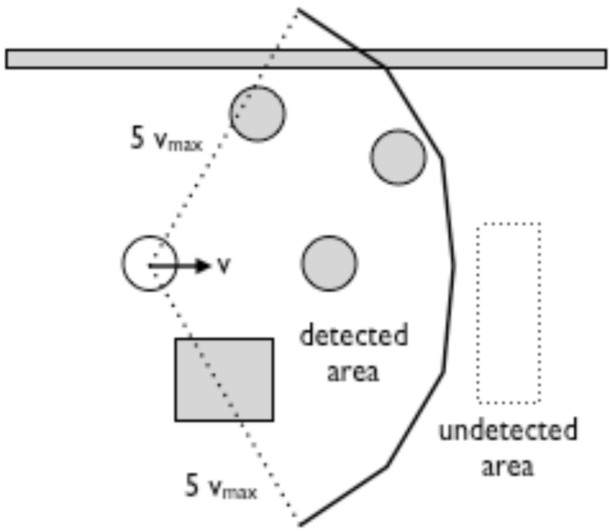

Figure 1. Scanning area of a pedestrian

The scanning area defines also the bounds for the decision making of the pedestrians next choice of speed and direction.

Choice set of speed and direction

To be able to enumerate the possible directions of a pedestrian to continue her or his way, the scanning area is divided in sectors (see Figure 2). While the angle is depending on the pedestrian type, the number of segments is constant among all pedestrians.

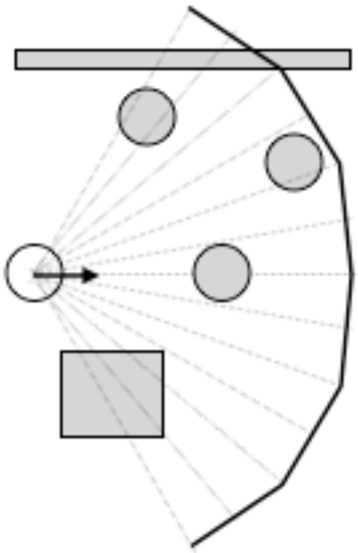

Figure 2. Search segments for speed and direction calculation

These segments are individually analysed to determine the maximum possible speed and therewith the utility of choosing the segment as direction. The smaller the scanning area angle, the finer the decision for directions, which allows for slight directional changes to avoid obstacles. The angle defined per pedestrian type is the maximum angle that can just be used in slow speeds. Based on observations, the changes in walking angles grow smaller with higher speeds. This phenomenon will be shown later with observations.

The scanning area is spanned around the initial walking direction of the pedestrian. This initial direction is the result of the actual walking direction and the direction to the destination of the pedestrian. Both directions get weighted depending on the distance to the destination, to ensure that even though pedestrians have a huge freedom of route choice, they will always arrive at their destination. Figure 3 indicates this rule.

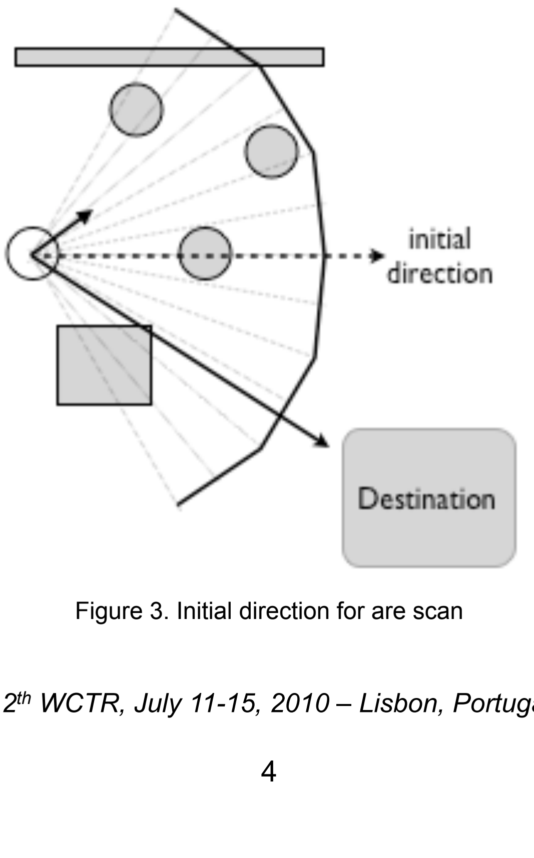

Figure 3. Initial direction for are scan

Having now the possibility to enumerate the choice of directions, the segments can be evaluated. To do this based on a snap shot of the simulation would be possible, but is unrealistic, since every pedestrian will anticipate on the behaviour of the pedestrians in front of her or him.

Anticipation

To include anticipation in our model, every pedestrian will run a short term simulation in her or his scanning area, assuming that each pedestrian in it will continue with the sam speed and in the same direction as of that moment. With this simulation, the pedestrian can calculate the time to collision for each segment in the scanning area. The result of such an simulation is shown in Figure 4.

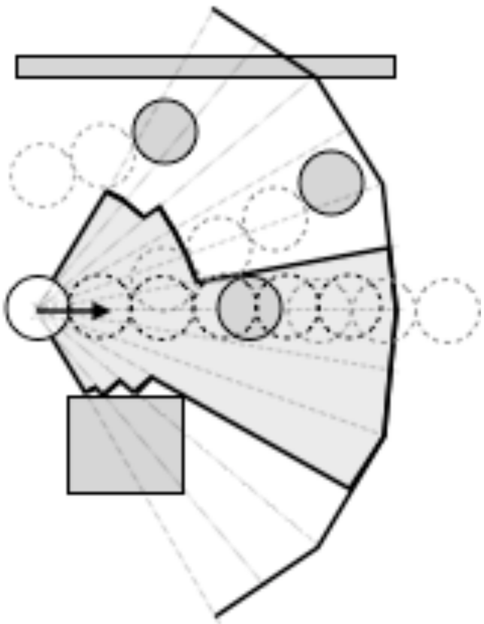

Figure 4. Anticipating speed and direction of other pedestrians

The grey area indicates the distance the pedestrian can walk in each direction without clashing with an object or a fellow pedestrian. The distance can be reduced to a utility for each segment and the pedestrian will chose the direction with the highest utility. If several segments have an identical utility value, the pedestrian will chose the segment closest to the initial position.
The reader may be reminded that the segmentation is already taking into account the pedestrian type and the actual speed, so that the highest utility segment will always be a feasible choice under the actual circumstances.

Route Choice

The actual version of the simulation focuses on pedestrian on crossroads, due to the available observation data. Therefore we only define areas on the pavement as origins and destination and pedestrians chose the shortest path between them. Trajectories, such as in Figure 5, occur due to the encounter with other pedestrians.

Figure 5. Possible route choice for crossing the street

Initial tests of the model and observations revealed that the behaviour differs in certain areas of the crossroad. Therefore we have defined three zones as indicated in Figure 6.

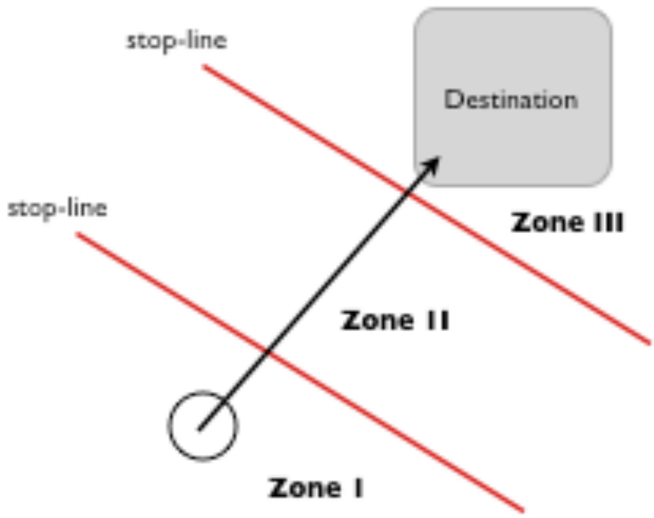

Figure 6. Different zones for route choice

During the queueing in front of the traffic light in zone I, the pedestrians will spread along the stop line, but the eagerness to pass other pedestrians is low. This avoids chaotic behaviour of pedestrians while waiting. In zone II the model acts as intended and in zone III we allow slightly more freedom to avoid clashes with the generated people.

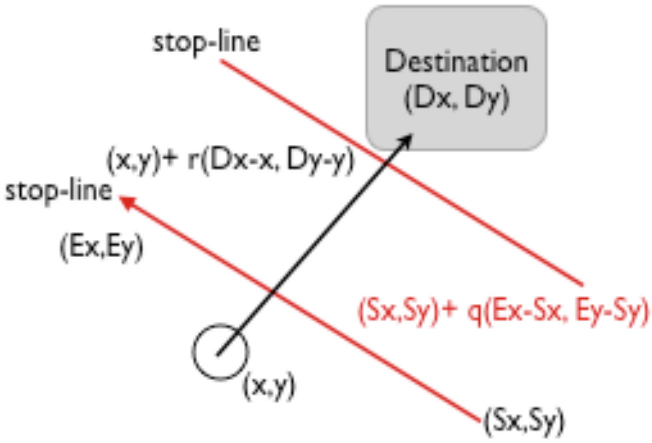

Figure 7. Determining the traffic lights to watch

To determine in which zone the pedestrian is and which traffic light she or he reacts on we calculate the intersections of the walking path with the stop lines of the traffic lights. This allows a quick evaluation of the zone the pedestrian is in and hence the behaviour. Further route choice, such as intermediate points or paths along further distances are so far not considered, but are indicated in the future work, where we try to extend the model to a wider region using GPS tracking data from cell phones.

Couples or Small Groups

Couples or small groups - mostly family - walking close to each other are treated separately in our model. We generally apply the same mechanism, but since we are dealing with two people, the size is doubled and the direction is assumed to be the centre of the couple and not one or the other person. Further we assume that couple do not split along there way. The assumption that couples do not break up along the way can be questioned of course, and that is why we have developed a theory on group behaviour, described in the following paragraph.

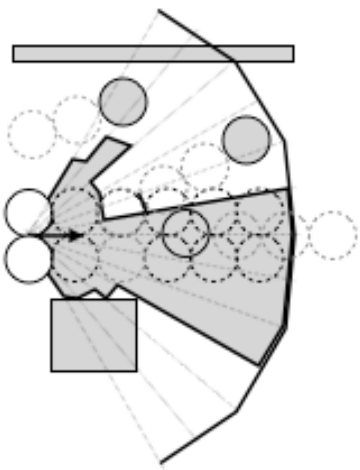

Figure 8. Anticipating speed and direction of other pedestrians

Movement equations

For every update each pedestrian calculates his or her desired direction based on the actual position and the gravity point of the destination zone.

$$\varphi_{desired} = atan \frac{(destination_y - position_y)}{destination_x - position_x}$$

Around the desired direction, in a sector of the angle phi, the pedestrian calculates the maximum distance he or she can walk under current dynamics without bumping into another person inside a limit of 3 seconds.

$$distance_{act,t,\phi} = Min \sqrt{(pedestrian_{act,t,\phi,x} - pedestrian_{i,x})^2 + (pedestrian_{act,t,\phi,y} - pedestrian_{i,y})^2}$$

with

$$direction_{act} - \frac{\varphi_{max}}{2} \leq \phi > direction_{act} + \frac{\varphi_{max}}{2} \text{, and } 0 < t \leq 3 \text{ sec}$$

The maximum distance is chosen, and with this the new angle walking angle phi. To determine the speed of the next movement, the distance is used to calculate the time to collision.

$$TTC_{\phi} = \frac{distance_{act,t,\phi}}{speed_{act}}$$

If the time to collision is greater than 1.2 seconds and the walking speed is below the desired walking speed, the pedestrian will accelerate. If the time to collision is smaller, the pedestrian will reduce speed, so that the time to collision will become 1.2 seconds. If walking with the desired speed in a safe condition, the speed will be remained.

MODELLING GROUP BEHAVIOUR

Next to single pedestrians, walking individually, we were interested in modelling the movement of bigger groups in the pedestrian stream. Unfortunately, we were not able to acquire appropriate video footage, so that we can just present our theory and have to leave the validation to future work. We distinguish between three different group types, which will be described below. We assume the key in group movement behaviour the connection between the group members, since this factor determines the probability of them being broken up and the way the reunite along their way

Type I: Follow the leader

This type might be best described as a tourist group following a tour guide. Individuals, including small groups and couples, are following independently a leader, with the only goal to stay in touch with the leader. In this scenario, only the leader of the group has a destination in the area. All followers have the moving leader as destination and hence keep following him. Figure 9 shows such a behaviour.

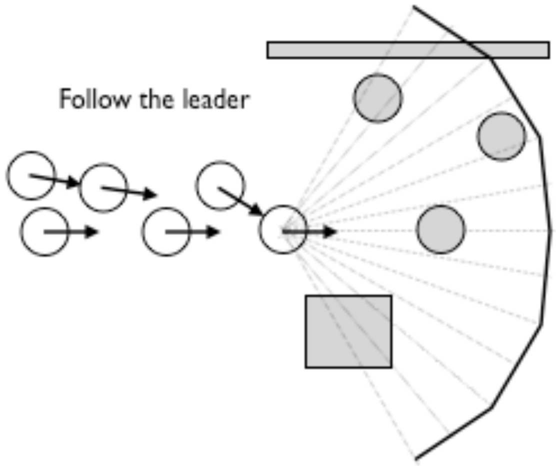

Figure 9. Group type1 - independently following the leader

The only interaction in this group is, that the leader is checking the distance between her or him and the following pedestrians. If this distance closes in or passes a threshold the leader will reduce speed or even wait for everybody to catch up.

Type II: Walking together

While a group of type I is composed by strangers, the group II is composed of people with a certain relationship and hence a higher connection force. In this group, every individual knows the destination and next to the group leader, we have introduced sub-group leaders who lead up to three persons. This group generally walks more like a group and not like a line of people. Additionally, when facing an obstacle this group is more flexible, can split up (since everybody knows where to go) and reunite behind the obstacle. To achieve this, the initial direction of every sub-group leader is set between the direction towards the group leader and the physical destination in the area. In the same fashion as group I, the leader is monitoring the distance to all members of the group and ensures that the distance is not greater than a given threshold.

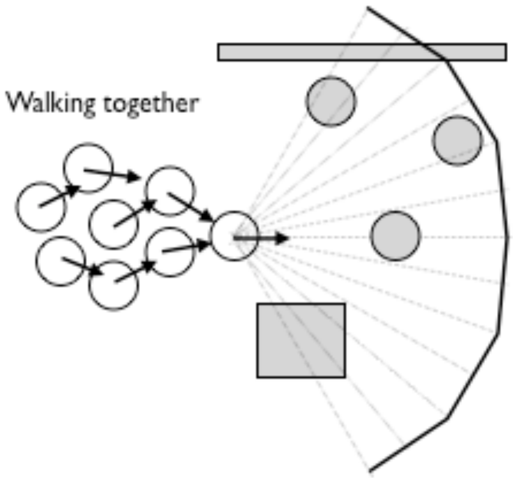

Figure 10. Group type 2 - walking together in a group

A further effect of the more group shaped formation is that pedestrians, walking in the opposite direction, are moving out of the way since a larger number of segments is effected during the decision making process.

Type III: Protective walking

A final group we have created due to special needed persons like mothers with children or elderly when included in a group. This group assumes a protective walking, which means that other group members are shielding the special person so to encounter less disruption from other pedestrians as shown in Figure 11.

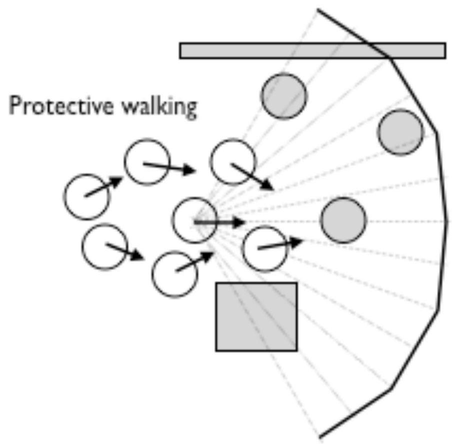

Figure 11. Group type 3 - Group walks to protect special person (mother & child, elderly)

In this group, the special person has the direction to the destination and the other group members are circling around that person in a short distance. This will cause a similar but less dense formation as for type II and hence, pedestrians coming the other way are tending to move out of the way.

PEDESTRIAN OBSERVATION

To calibrate the parameters of our model we have used high definition video footage of the Shibuya crossing in downtown Tokyo, which we have observed from a high rise building. The video has been taken for 24 hours to evaluate a variety of situations. The area is shown in Figure 12. In the west of the area is Shibuya station, one of the busiest stations in Tokyo and the main stream of people walks between this station and a huge shopping district located in the northeast corner. During the day there is an average of 250 people crossing the intersection in one cycle. About 68% of this volume is found on the diagonal crossing stretching from the northeast to the southwest of the area.

Figure 12 – Shibuya crossing in downtown Tokyo observed from a high rise building with high definition video camera

All described observations from now are taken from mid-day cycles and divided into pedestrians having luggage or a pram, people in an obvious hurry (average speed above 1.8m/s) and small groups or couples.
Figure 13 shows the distribution of speeds for these groups of pedestrians. The number in the legend depicts the sample size. It can be seen that small groups and pedestrians with prams or luggage are generally walking slowly and have a small standard deviation in speed. If in a hurry, pedestrians have a higher speed and the standard variation is also high. The average of 2.29 m/s is assumed to be a bit too low, since the amount of pedestrians will not necessarily allow those people to reach their desired speed.

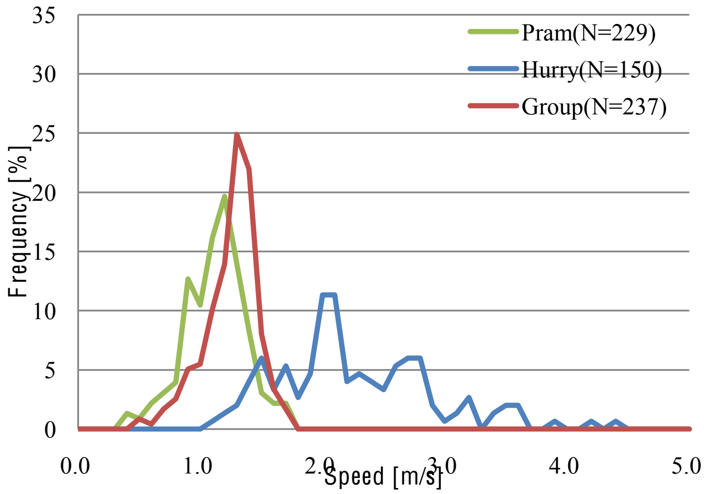

Figure 13 – Speed distribution for pedestrians with pram, hurried pedestrians and groups

As mentioned in the modelling paragraph, we assume that the changes in walking direction grow smaller with higher speed. Figure 14 is showing the observations made at the intersection. It can be concluded that the changes in direction at a speed of 1m/s are indeed higher than at 2 m/s and much higher that at speeds higher than 3 m/s.

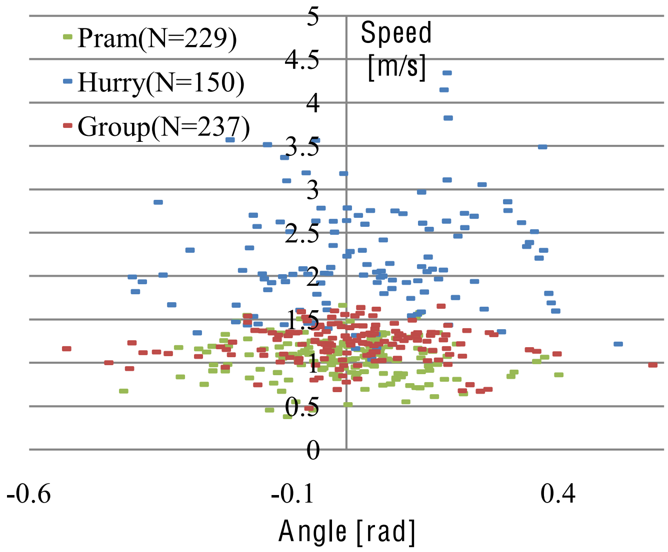

Figure 14 – Changes in walking angles under given walking speeds

It also shows that pedestrians with luggage or prams are having the smallest changes in angle among the pedestrian groups we have analysed. Figure 15 shows the cumulative curve for the observation.

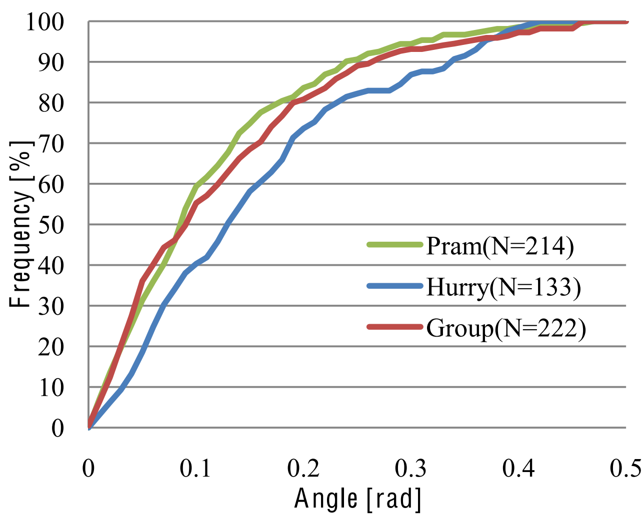

Figure 15 – Cumulative curve of walking angle changes

All parameters from the observation that are used in the model are summarised in Table 1. The parameters include the average speed and its standard deviation, the pedestrian size (in walking direction) and the observation angle.

Table 1 – Simulation parameters based on video observation

Parameter	Pram	Hurry	Group	Normal
avg. speed	1.03	2.29	1.21	1.35
speed variation	0.48	0.71	0.51	0.45
size	0.6	0.2	0.3	0.3
observation angle	20	80	30	60

SIMULATION

Using the parameters from Table 1 we have simulated the are in our microscopic simulator. Even though preliminary results were promising we run a calibration process, varying all parameters in feasible boundaries to find the best parameter set to match the data. Slight variation in the speeds and searching angles resulted in satisfactory results which will be shown in the following.

The speed distribution shown in Figure 17 is the results of a simulation of about 50 cycles of pedestrian movement. The results show the movements in zone II, which excludes the queueing at the traffic light and the arrival at the destination. The profiles show a good match, and as assumed in the observation already, the desired speed of the pedestrians in a hurry had to be increased by about 0.4 m/s to match the observations.

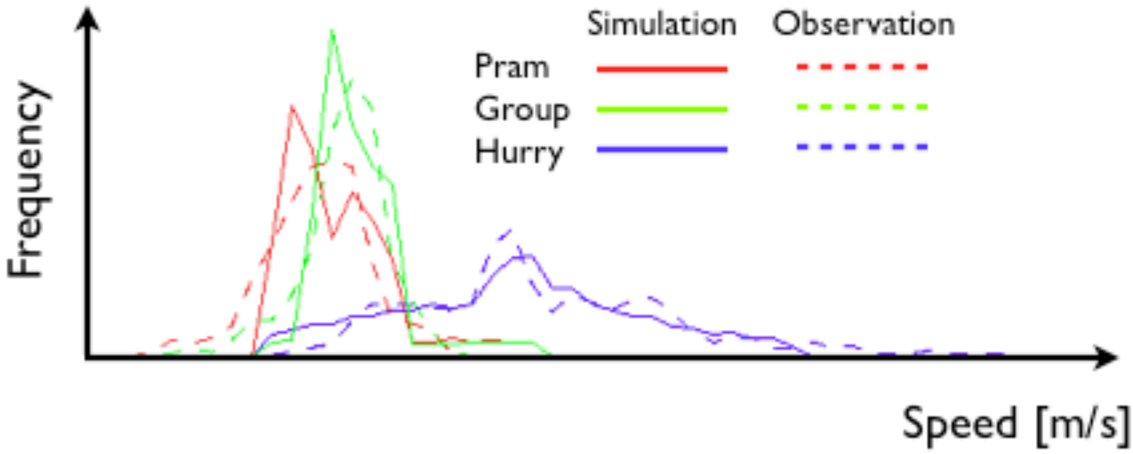

Figure 17 – Speed distribution comparison between the simulation and the observations.

However, in contrast to the observations and as shown in Figure 19, the pedestrians in a hurry tend to make less radical direction changes than in reality. Matching the observation curve has lead to unfeasible parameter settings, and so we assume that pedestrians in a hurry might change destinations along the way or utilise a more wider area of the crossing than allowed by our model. Since we have restricted the walking area for pedestrians with the initialised direction based on the destination. While we find, as in reality a utilisation of the pedestrian crossing beyond the markings, some areas we have observed pedestrians are left out in the simulation. However, an increase of the area has shown unfeasible results for lower demand.

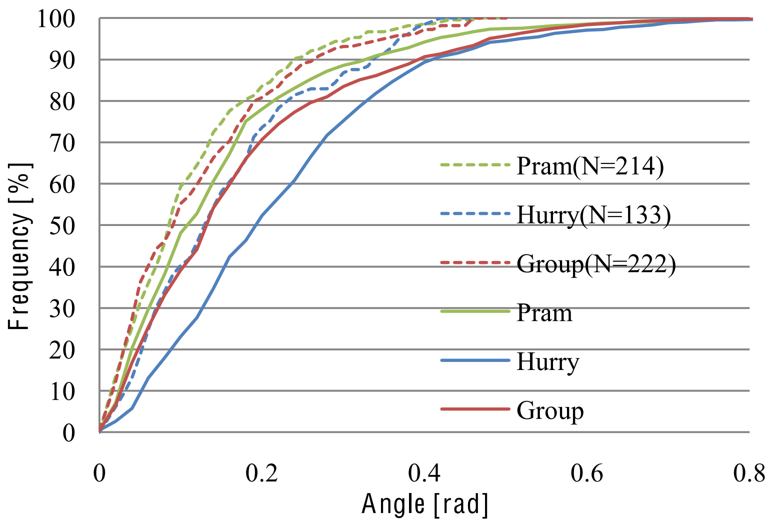

Figure 19 – Cumulative curve of walking angle changes

The parameters found as best set to match the observation is summarised in Table 2, which is slightly changed from Table 1.

Table 2 – Calibrated parameters

Parameter	Pram	Hurry	Group	Normal
avg. speed	1.15	2.70	1.26	1.85
speed variation	0.3	0.75	0.20	0.25
size	0.6	0.2	0.3	0.3
observation angle	30	80	40	60

CONCLUSIONS

In this paper we have analysed the observation data of a high demand pedestrian crossing in downtown Tokyo divided for three different pedestrian groups. We have found that pedestrians, depending on their desired speeds are scanning a certain area to chose their directions and that the changes of direction are getting smaller with increasing speed.
The extracted data we have used to calibrate a microscopic simulation model that considers the heterogeneity of the crowed. We were able to reproduce the observation for the pedestrian crossing and have added a modelling approach to extend the model with movements of larger groups, depending on their connectivity. During the calibration process it was found that the average desired speed of pedestrians in a hurry is likely higher than the average observed speed. Further, given discrepancies between the simulation and observation, we have to conclude that pedestrians with a high desired speed are not necessarily looking for the shortest path, but might do longer distance plans to walk in areas with low density, when in a free space. While our model, as most pedestrian models for bounded walk passages assumes an optimisation of the route in a confined space, this seems not to apply in open areas, where the bounds are as loose as pedestrian crossing lane markings.
Future work will include the test of the model in a different environment, like high demand train or subway stations, where the pedestrian flow is so dense that heterogeneity is cause for disruption due to the lack of space. Additionally, we are interested in finding data for calibration of the movement behaviour of larger groups. The model, so far based on personal observations needs to be examined by using real-world observation.
We also want to extend the model to a wider area, adding a route choice model based on GPS tracking data of a cell phone company in the Shibuya area. This combination aims to result into a pedestrian assignment model for areas with high demand sources, like train stations, and high demand sinks, such as festivals, shopping malls, and alike. Such a model could be used during the planning of events, attracting a huge number of people and to predict their flow through an urban area. Japan, with its dense populated areas is facing such tasks around the year and more knowledge will lead to better organisation and safer environments.

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