A simulation analysis for pedestrian flow management

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Summary. An agent simulation test model for pedestrian flow has already been developed, but an experimental simulation that incorporates actual data about an accident has not been designed. In our research, we have reconstructed this accident by improving an existing test model. Based on the accident report and using data gained through spatial research we have revised a pedestrian flow simulator. Through a simulation analysis including rows of standing people and the confrontation of the ascent and descent flows, we have explored measures to prevent a pedestrian accident. The ASPF is to assess measures for managing pedestrian flows by focusing on the domino risk rather than a reconstruction of crowd collapse as in the overpass accident. The simulation results show that a two-way flow, combined with stationary people can trigger an accident even on an overpass that satisfies present design standards. Moreover, we have confirmed that even simple traffic regulations such as partitions can be an effective measure to prevent a pedestrian accident.

Key words. Agent-Based Simulation, Pedestrian Flow, Accident Analysis

1. Introduction

An agent simulation test model for pedestrian flow has already been developed (Kaneda, et.al, (2002)), but an experimental simulation that incorporates actual data about an accident has not been designed. On 21 July 2001, 11 people were killed and 247 injured on the Asagiri Station Pedestrian Overpass. The overpass was near the venue for a fireworks display and this tragic disaster occurred when visitors gathering to view the fireworks were caught up in an uncontrollable rush and the crowd collapsed. In January 2002, the official Accident Investigation Report (Akashi City, (2002)) was released and detailed accident information was revealed.

In our research, we have reconstructed this accident by improving an existing test model. Based on the accident report and using data gained through academic spatial researches we have revised a pedestrian flow simulator, and through a simulation analysis including rows of standing people and the flow coefficients of the ascent and descent flows we have explored measures to manage pedestrian flows confrontation.

2. The design principles of a simulation model to examine a pedestrian accident

In an agent simulation model of a cell automata type, discrete approximation restrictions relate to each cell space. In order to choose suitable protocols for the model, we selected relevant data from the accident report as follows (See Appendix).

The accident report concluded the cause of the accident was a phenomenon known as crowd collapse which occurred when the maximum crowd density on the pedestrian overpass reached 13 to 15 person/m^2 (C. ②). In contrast domino phenomena occur with a density of only 3 to 5 (F. ①, ②) and many such accidents have been reported in the past. In our research we assumed a density of 4 as the danger value representing congestion (D. ①). We then reconstructed the incident in our model and examined measures to manage pedestrian flows safely.

Next, we shall focus attention on ways of dealing with the flow coefficient. The Asagiri Pedestrian Overpass was designed with an evacuation plan standard of 1.5 person/m · sec, which is far higher than the design standard of 0.33 person/m · sec (A. ③④). However, both values assume a one-way flow. The flow coefficient value at the time of the accident was estimated as only 0.48 at the peak time; only about one third of the maximum capacity (D. ①) and in spite of this low value, the accident still occurred.

The accident report states contributory factors to the accident were: 1) two counter flows meeting and becoming tangled up (F. ④), and 2) fireworks spectators blocking the area around the stairs of the pedestrian overpass (J). Our research model is therefore designed to examine the effects of these factors.

The accident report also states that effective crowd management measures were not carried out. (J. II). Our simulation experiment examines the effect of placing a partition in the middle of the pedestrian overpass.

3. The development of ASPF with an agent based approach

3.1 Revision of ASPF

It is known that existing pedestrian simulations on the cell-space adopt cellular automata (CA) models (Muramtatsu et.al (1999), Fukui, Ishibashi (1999)) or CA-derived agent models (Burstedde et.al (2001), Blue, Adler (2001)). In this study we have revised The ASPF (Agent Simulation of Pedestrian Flow, Kaneda et.al (2002)) that was implemented on a multi agent simulation software, kk-MAS.

In the ASPF spatial scale, walking spaces are represented by 40 square cm cells and the time scale is set at one step per 0.5 seconds. An L-shaped section of the accident area was modeled as follows: a space 6.8m (17 cells) wide and 40m long represents the overpass and the stairs are 3.6m (9 cells) wide and 25.6m long giving a total modeled area of $386.6m^2$ (2,416 cells). This model covers approximately 50% of the usable area of the actual overpass, however, the difference between stairs has been eliminated. The basic rule is only one person may enter a cell, but in areas of high density walking, with a surrounding density of 2 or more, two persons may enter a cell at the bend of the L-shaped space, giving a possible maximum theoretical density of 12.5.

3.2 A summary of agent walking behavior rules

In our research, based on the selective report data mentioned in the previous section, we added or changed the walking behavior rules, so as to conform to this data. Fig. 1 shows the simulation algorithm of ASPF determined as a result of trial and error.

The behavior rules for each agent are applied in the following order: ① a cornering rule, ② a direction change rule and ③ a walking behavior rule (Fig. 1). There are a total of 22 walking behavior rules applied to the agents: 6 basic behavior rules, 8 rules for slowing down in response to agents, 4 rules for avoiding agents, 3 rules for high density walking and 1 reading flow rule (Fig. 2)

We will now explain the walking behavior rules in more detail.

The basic behavior rules are applied when an agent is walking in a low density situation (density 2 or less). In rules ⑤ and ⑥ the number of cells to move forward is determined by a random number.

When slowing down in response to other agents, in a low density walking situation, the agent keeps a distance from agents behind and in front. The agent is forced to slow down in response to other agents, however, in rules ⑦ to ⑪, random numbers are used to decide forward movement.

When avoiding agents, in a low density walking situation, the rules maintain a distance between agents on the left and right sides.

In a high density walking situation (density 2 or more), the rules decrease the distance between agents in front and behind, but maintain the same distance to other agents on the left and right sides.

The flow reading rule regulates whether agents follow or avoid other agents by looking at the cells to the right of the direction of flow.

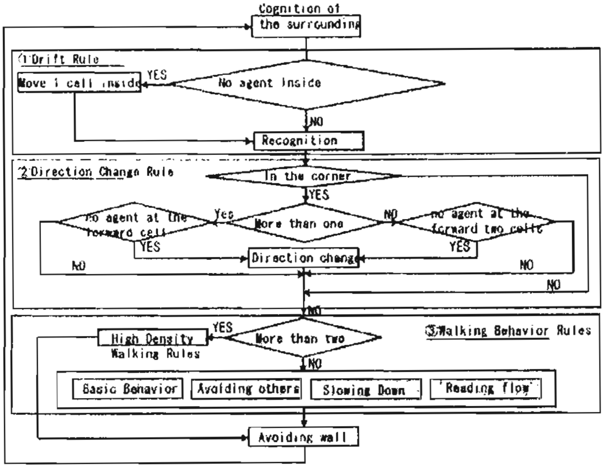

Fig. 1. Algorithm of Pedestrian Agent in ASPF

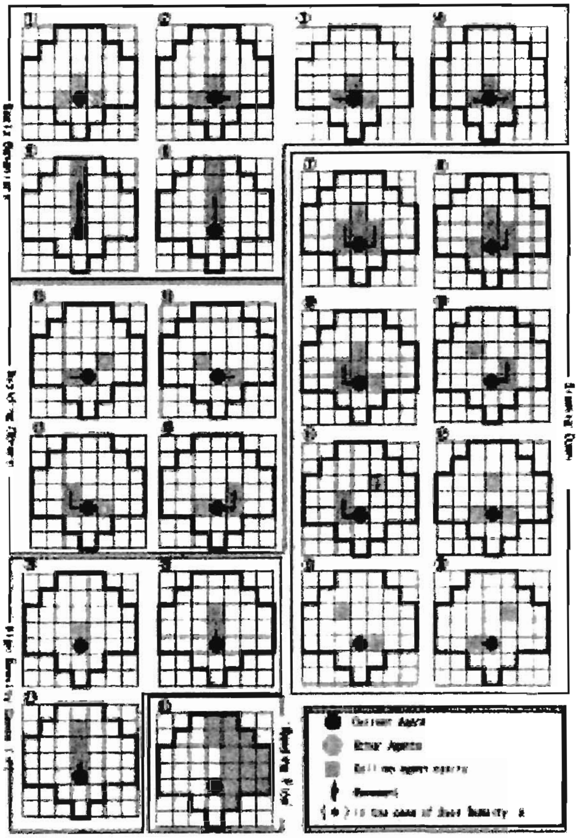

Fig. 2. Agent walking rules

3.3 Benchmarking of the forward flow

Many academic spatial researchers have examined the direction of flow and the relation between density and flow speed. Fig. 3 is a graph to show this relation (Architectural Institute of Japan (2003)). At this point we added the simulation performances of the forward flow given in ASPF to Fig. 3. The relation between density and flow speed in the revised simulation model revised gave a good approximation of the actual walking flow.

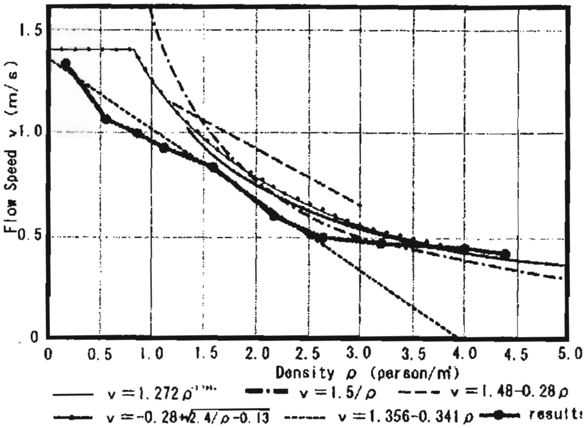

Fig. 3. Benchmarking of agent speed (forward flow)

3.4 About pedestrian's cornering behavior: 'ascent' and 'descent'

According to the accident report, the flow on the overpass from the venue to the station ('ascent' flow) shown in Fig. 4 (b) met and conflicted with the flow from the station to the venue ('descent' flow) shown in Fig. 4 (a) when moving round from the stairs to the east side of the overpass (Fig. 4 (c)). The descent flow was then pushed over to the west side and compressed. The report mentions both flows experienced friction on the north-east diagonal line from the corner between the overpass and the stairs and this situation was partly responsible for the accident (F. ④).

The micro-motive of pedestrians relating to cornering behavior can best be explained by comparing their behavior to car driving techniques. In other words, agents in the southern descent flow tend to move towards the inside (the right side of the direction of movement) and after turning right, swing over towards the outside (the left side). In this case, since there is a clear view of the south side of the stairs, this tendency naturally increases. In the same way, the ascent flow is to the east and inside (the left side), and when moving to the north, swing over towards the outside (the right side) (Fig. 4).

In order to include this cornering behavior in the simulation model, we introduced a cornering rule. This rule is applied before the direction change rule and under this rule an agent moves inside when the inside adjacent cells are vacant.

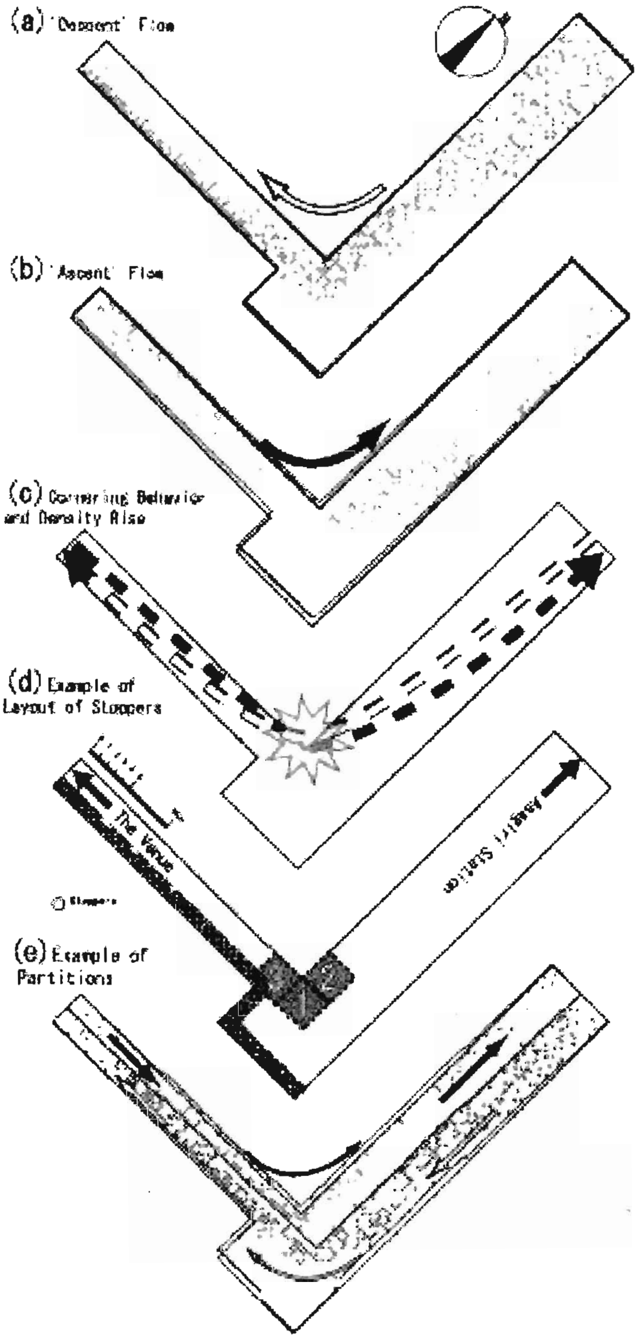

Fig. 4. Spatial model and density distributions

4. A simulation analysis by using the ASPF

4.1 Summary of the simulation experiment

The accident report mentioned the existence of these two counter flows and the occupation of space by standing people, however, it did not estimate any figures for either situation. In our research we conducted a simulation experiment to determine both the numbers standing and also those involved in the counter flows.

For this simulation, we combined five flow coefficients 0, 0.5, 1.0, 1.5, 2.0 for each ascent and descent flow, and 6 layouts for standing people (hereinafter referred to as 'stoppers'), a baseline case (no 'stopper'), 2, 3, 4, 5 rows and traffic regulations (Fig. 4 (d), (e)).

(Earlier some coefficients even with no stoppers gave an extremely high density increase and after stoppers were included, we decided not to use these coefficients).

Fig. 4 (d) shows three areas of high density measurements that correspond to areas on the accident report map, where there was a high concentration of fallen people. Area 2 is mentioned in the report as the place where the crowd collapse occurred.

In the simulation experiment we used a step value of 200 (100 seconds) and this gave a constant number of agents and density for each area. Experimental results were obtained by calculating the average of 5 or 10 simulations.

The traffic regulation shown in Fig. 4 (e) is a spatial model where ascent and descent flows are separated by installing a partition in the middle of the agent's walking space.

4.2 Simulation results and analysis

Fig. 5 shows the simulation results. With a one-way flow, some cases exceeded the danger value in area 2 ($\alpha = 2.0$, $\beta = 0$), but all the other cases were below the danger threshold. These results clearly show that Asagiri Pedestrian Overpass satisfied an evacuation plan standard of 1.5.

In the case of a two-way flow, an increase of density can be seen compared with a one-way flow. In particular, in the case of $\alpha = 1.5$ or more, this tendency is very noticeable. In the case of $\alpha = 1.5$, $\beta = 0.5$, some areas exceeded the danger value. In the case of $\alpha = 1.5$ or more, the density of area 2 is higher than that of area 2 or 3. It can also be seen that the increase of density in area 2 ripples out and through to area 1 and 3.

Next, we focus on the number of stoppers rows. The stoppers differ depending on the scale of the flow coefficients, where both flow coefficients are small (giving a combined total of 2 or less), the increase of density in area 3 is more marked than in area 1 or 2. This indicates that stoppers are responsible for the increase in density in area 3. When both flow coefficients α and β are large, the reverse is seen, the density in area 1 or 2 becomes higher than in area 3. The density increase in area 3 appears to cause the density increase in area 1 and 2.

When we introduced a partition to regulate the flow of traffic, the number of cases showing danger values was reduced. For example, in the case of $\alpha = 1.5$, $\beta = 0.5$, the density of area 2 became 25% of the baseline case with no regulation. This demonstrates that the congestion mechanism that caused the spread from area 2 was eliminated by the introduction of traffic regulation. However, with traffic regulation, when the flow coefficients of ascent and descent flow are small, the path width for agents is set and naturally the density tended to be higher compared to no traffic regulation.

5. Conclusion

In this research we have reported the development of the ASPF incorporating information from both the accident report and spatial research. The ASPF has explored measures to prevent an accident by focusing on the domino risk rather than a reconstruction of crowd collapse as in the overpass accident. The simulation results show that a two-way flow, combined with stationary people can trigger an accident even on an overpass that satisfies present design standards. Moreover, we have confirmed that even simple traffic regulations such as partitions can be an effective measure to prevent a pedestrian accident. The results of our simulation underline the highly practical application of ASPF.

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