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A Study on Pedestrian Flow by Using an Agent Model —A Simulation Analysis on the Asagiri Overpass Accident, 2001—

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Summary. The purpose of this paper is to analyze pedestrian flows on road crossing and overpasses through applying agent-based simulation that has pedestrian's 18 behavioral rules on cellular-automata space. As a case study of high-density flow simulation, the authors try to trace an occurrence process of the accident of Asagiri Pedestrian Overpass, Akashi City, which several news media had reported, by the 'falling down like ninepins by confrontation flows' hypothesis.
In the low-density case, through comparing between the simulation results and the survey data, we have verified similar patterns of the pedestrian flow under our devised rule conditions. In the high-density case, under an assumption of the confrontation flows hypothesis, we verified that the point triggered the actual accident and the simulation result coincided nearly. Thus, our agent simulation has the potentials to get insightful suggestions on analyses on pedestrians' accidents.

Keyword. Agent-Base Simulation, Pedestrian Flow, Accident Analysis

1 Introduction

Recently, agent simulation technique gets popular for research on the complex systems. Till now the effective methodology didn't exist to tie to various factors, and the complex system couldn't check a hypothesis in the scientific method. But now it is developed road traffic in the whole area of the city can be reproduced (TRANSIMS in Casti (1996)) due to the development of the computer. The purpose of this paper is to analyze pedestrian flows on road crossing and overpasses through applying agent-based simulation that includes pedestrian's behavioral rules on cellular-automata space. Our approach aims at tracing an occurrence process of the accident, mainly based on the 'falling down like ninepins by confrontation flows' hypothesis that several news media had reported at first.

2 Design and Development of Pedestrian Flow Simulator

2.1 The Design of the Agent Behavior Rule

Characteristics by the crowd density are known (for example, Table 1), and the confrontation way of the pedestrian can think that it caused for other individual potential and other individual avoidance potential and so on as an accumulation of each pedestrian behavior. In this research, the behavior rule of five kinds and total eighteen agents was laid down as shown in Fig 2. Those five kinds of groups of rules were given the applicable order it in Fig 1.

And, as for (5), the direction of the agent that it is the area of the slant line is totaled. Then, it was decided following and avoidance about the absolute value of the difference as a threshold.

2.2 Spatial Scaling

We have applied a pedestrian flow model by using MAS (Multi-Agent-Simulator), developed by Kozo-Keikaku Engineering and Inc. In our model, the walking space is divided by the cell of 45cm square. So, each agent can exist in only one cell, and each cell can occupy only one agent. The time step is defined as 0.5second in the real world. In each step, the simulator firstly makes the order of the moves of all agents randomly, and after moving all of them over, it get forward to the next step.

2.3 Pedestrian Agent Model

Framework of Agent Behavior

Each agent behavior depends on the pedestrian density around him/her and other agents in his/her sight. An individual agent is devised to cover the range of four cells in the front, three right and left and two to back. Then, the five-rank priority for applying each agent's behavioral rules is devised, that enables each agent to check the situation, to seek the rule and to make his/her behavior. Now and we explain how each agent decides his/her walking speed adapting to the surrounding density.

Four categories of the walking speed are devised corresponding to the pedestrian density.

First, when the density is < 0.3 person/m^2, an agent moves two cells forward (means 1.3m/s walking speed). In case of 0.3 - 0.7 person/m^2, he/she moves one or two cells forward by even possibility's (means 1.0 m/s walking speed), in the case of 0.7 - 1.4 person/m^2, he/she moves one cell (means 0.7 m/s walking speed). When > 1.4 person/m^2, he/she moves one or no cell forward by even possibility's (0.4 m/s walking speed). Thus, the walking speed was taken into consideration only like this basic behavior rules. It isn't taken into consideration about the walking speed at the Rank 2-5 rules are given the conditions such as crowd density.

Table 1. Pedestraian Density and Walking Speed (Sakakibara, 1990)

	Pedestrian Density (person/m2)	Walking Speed (m/s)	Traffic Volume	Choice of Speed	Conflict	Passing
High-Density Flow	2.0-5.0	Less than 0.4	Almost Stop	Impossible	Unavoidable physical to touch	Impossible
	1.4-2.0		The maximum volume under pressured condition	Impossible Almost same speed to a crowd	Possible to physical touch unavoidable to conflict	Impossible
Low-Density Flow	1.0-1.4	0.4-0.7	The maximum volume under loose condition	Difficult	As above	Impossible
	0.7-1.0		65%~80% of the maximum volume	Constrained Need to keep step with a crowd	Unavoidable	Rarely possible to no-touch
	0.6-0.7	0.7-1.0	56%~70% of the maximum volume	Constrained except slow Pedestrian	High Risk	As above
	0.4-0.6		About 50% of the maximum volume	Possible to be constrained	As above	Possible if you turn round
	0.3-0.4		About 33% of the maximum volume	Sometimes constrained	About 50% probability	Possible but constrained
	Less than 0.3	1.0-1.3	Less than 20% of the maximum volume	No-Constrained	Need to avoid	Free but need to avoid

Behavioral Rules of Agent

The behavioral rules of an agent are devised for considering the walking speed and the surrounding crowd density. Our devised rules have the five-ranked priority. (Fig1, 2) The first-ranked rule is called the Basic Behavior Rules. This consists of seven rules.

Rank1 (1) Basic Behavior Rule (Seven Rules)
Not to overlap one another.
To decide the speed corresponding the surrounding density.

⇩

Rank2 (2)Slow-down Rule (Three Rules)
In case of low-speed, to keep span to front and back pedestrians.

⇩

Rank3 (3)Evading Rule (Four Rules)
In case of low-speed, to keep span to right and left ones.

⇩

Rank4 (4)High density Flow Rule (Three Rules)
In case High speed, to reduce span to front and back ward pedestrians rather than right and left

⇩

Rank5 (5)Pattern Cognition Rule (One Rule)
Scanning the sight zone, decide wether to follow or avoid the crowd.

Fig. 1. Priority on Applying Behavioral Rules

- (a) He/She stops at that place when other agents exist in the front, right and left.
- (b) He/She moves one cell to the right when other agents exit in the front and left, and another agent doesn't exist in the right,
- (c) He/She moves one cell to the left when other agents exit in the front and right, and another agent doesn't exist in the left.
- (d) He/She moves one cell to right or left when other agent exists in the front, and other agents don't exist right and left.
- (e) He/She moves one cell to the front when other agent exists in the front four cells at the case of the crowd density ≧ 2.0.
- (f) He/She moves two cells to the front when other agent doesn't exist in the front four cells at the case of the crowd density $<$ 2.0.
- (g) He/She moves one cell to the front, or stops at that place by the random numbers when another agent exists four previous cell and another agent doesn't exist three previous cell.

The second-ranked is called the Slow-Down Rules. This consists of three rules.

- (h) He/She moves one cell to right or left, that is depending on the random numbers when another agent exists in two previous cell and another agent doesn't exist in the one previous cell.
- (i) He/She moves one cell to right when other agent exists in the place of the figure, and other agent doesn't exist in the right and left cell.

- (j) He/She moves one cell to the left when another agent exists in the place of the figure, and other agents don't exist in the right and left cell.

The third-ranked is called the Evading Rule. This consists of Four Rules.

- (k) He/She moves one cell to the right when another agent exists in the left cell, and another agent doesn't exist in the right cell.
- (l) He/She moves one cell to the left when another agent exists in the right cell, and another agent doesn't exist in the left cell.
- (m) He/She moves one cell to the left when another agent exists in the left slant cell, and another agent doesn't exist in the right cell.
- (n) He/She moves one cell to the right when another agent exists in the right slant cell, and another agent doesn't exist in the left cell.

The forth-ranked is called the High Density Flow Rule. This consists of Three Rules.

- (o) He/She stops at that place, when another agent exists in the previous cell at the case of the crowd density ≧ 2.0.
- (p) He/She moves one cell to the front when another agent exists in two previous cell at the case of the crowd density ≧ 2.0.
- (q) He/She moves one cell to the front when another agent exists in the three previous cell at the case of crowd density ≧ 2.0.

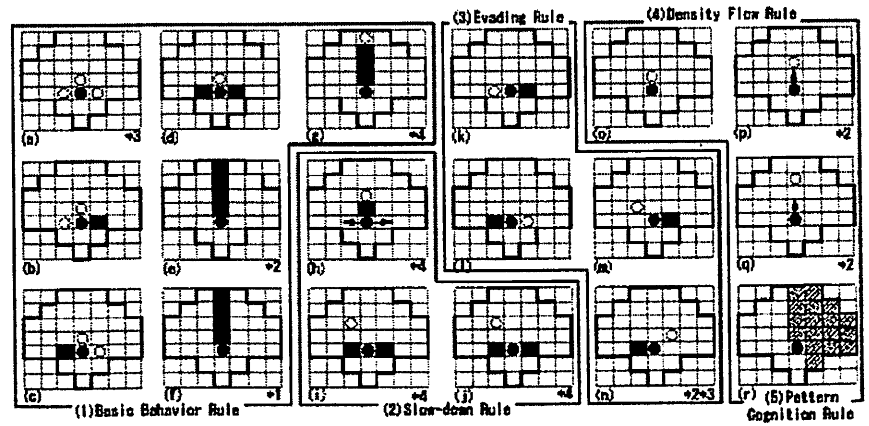

Fig. 2. Behavioral Rules of Pedestrian Agent black circle: Cell where the agent exists currently, circle: Cell where other agent exists, gray square: Cell where no agent exists, square: Cell unrelated to his/her exists, *1: the density <2, *2: the density ≧2, *3: to stop, *4: to stop randomly, bold line: The sight of the agent, line: Zone to measure the pedestrian density

The fifth-ranked is called the Pattern Cognition Rules. This consists of One Rules.

- (r) His/Her following or avoidance are decided as a threshold what is the absolute value of the difference after add up the direction of the agents in the slant line area.

3 Simulation Analysis on Low Density Pedestrian Flow – A Case Study on Pedestrian Crossing –

3.1 Outline of the Simulation

We think about a walking space model first, to simulate low density crowd flowing. We arrange each 31points, that is a walker occurrence point and a vanishing point, on the both walker entrance sides as pedestrian crossing of the length 18m and width 14m.

3.2 Results, Analysis and Consideration

When the simulation run after setting the flow volumes from the both sides on 26 person/m · min, the highest density once became 1.2 person/m^2 then decreased to about 1.0 person/m^2 and got stable. This can be restated that agents avoid each other and try to prevent collisions as if each of them has consciousness. And, the following agent comes to take the action that followed the agent in the same direction, and the agents in the same direction gradually occur confrontation flow that makes a group. It follow in density's increasing, that the thickness of the confrontation way becomes sharp, and comes to form some belt-shaped layer. Crowd flowing comes to flow smoothly, and settles down steady condition when a stratification phenomenon begins to happen because scenes like avoidance of the collision with the confrontation person decrease. (Fig.3)

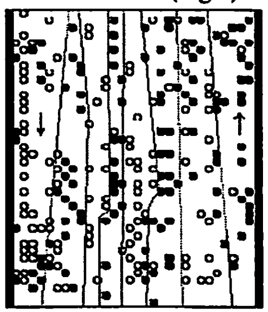

Fig. 3. Example of Low-Density Flow Simulation

3.3 Comparison to the Actual Survey

Here, we confirm how the behaviors of our devised agents are close to the reality in the low density flow by the comparison with the actual survey results. For the comparison, we quote Kato and his colleges' study at pedestrian crossing in The Sukiya Bridge. Their survey results show that mutual avoidance to avoid the collision, follower's flow, confrontation flow, and stratification phenomenon due to density increase, as well. It is confirmed that our model can simulate the actual pedestrian flow in the case of low density.

4 Simulation Analysis on High Density Pedestrian Flow – A Case Study on Asagiri Overpass Accident –

4.1 Outline

Case Study Space

In this paper, we deal with Asagiri Pedestrian Overpass, Akashi City,Hyogo Pref, as a case study of high density flow simulation. This is the place where the accident had happened on July 21, 2001 at about 8:00pm and eleven people were killed and 247 injured. Then in the day of the fireworks festival, many sightseeing visitors had felled down on upon another (Fig, 4).
In this study, the accident spot was imitated and a pedestrian overpass was modeled around the place to have the pedestrian overpass of the width 6m length 102m of the horizontal way, the width 3m length 18.5m of the stars and width 6.3m vertical width overpass.

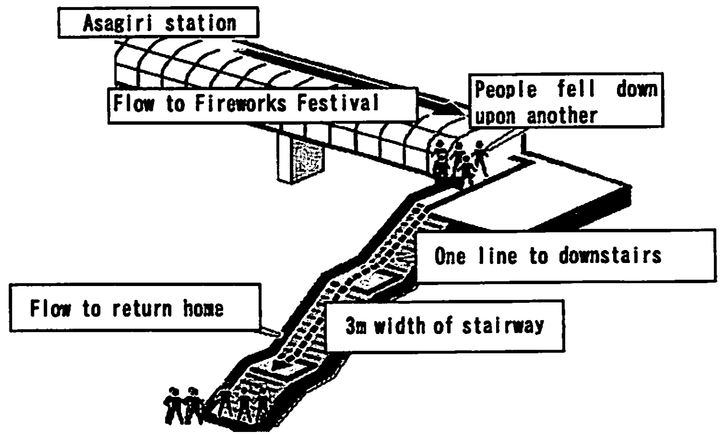

Fig. 4. Asagiri Accident Situation, July 21, 2001

Revise of the Agent Simulation Model

The Revise of the agent is necessary, that is given here when simulate the high density crowd flowing which made case of Asagiri pedestrian overpass. First one, we add direction change rules, which is necessary because the stairs and the horizontal way intersect with the right angle. The direction change rules are as the following. First, the direction change is done when other agent doesn't exist in front of two cells for the direction which turning case of the neighborhood around the agent is low density, even in front of two cells. And, direction change is done when an agent doesn't exist with one cell and others in the direction, which turns in case of high density. And, even if this condition was satisfied, it didn't turn, but the case of didn't turn or the case of turned was made to show visually natural flow stay rules as follows by the random numbers. Next additional rules is staying rules, that walker from the station had a mind taken by a firework at the end of the south of the pedestrian overpass, based on the reference of the newspaper account that it stopped and staying occurred. And, the rate of the walker to stay can be changed rule by the random numbers with a direction change rules. The structure of the walker direction change rules and staying rules are shown in Fig.5. And, with simulation, to make Area1, Area2 and Area3 for easy to understand the cause of the accident, a person stops the place where staying happened, the place where falling down one upon another actually happened, the place to consider for density that to rise because the stairs and horizontal deck crossing of acquaintance width becomes small in case of a pedestrian overpass accident. (An area for the density measurement is shown with Fig.6.)

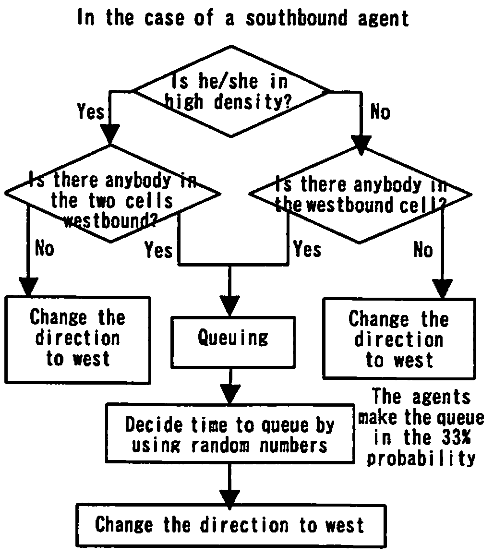

Fig. 5. Direction-Change Rules and Queuing Rules

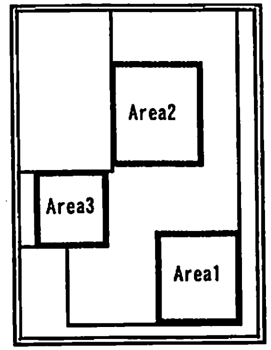

Fig. 6. Areas whose density we focus Area 1: The place many people stopped to watch fireworks when the accident happened. Area 2: The place people fell down upon another. Area 3: The place where the density is high because of crossing the pedestrian deck and the stairway.

4.2 Results

Results on Various Case Settings

Fig,7(a) is a snapshot of the walking space in 210 step progress in case of the flow volumes from the both side of the station and the stairway at 72 person/meter · minute. When we focus the stairs side and station side entrances, there seems more agent at the stairway side than the station side, it is the reason that agent from the station flowed into the narrower width of the stairs. A walking flows smoothly because two layer of flow is formed in the stairs and the horizontal deck.

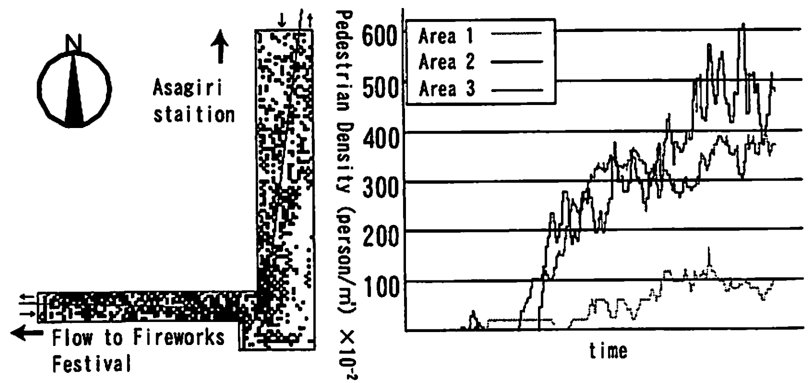

Fig. 7(a). Snapshot on Asagiri Pedestrian Overpass. (b) Trajectories of Pedestrian Density (Flow volume 72 person/m * min, Standard queuing of probability 33%)

Next, we set the flow volume from the both side of the station and the stairs at 36person/m • min, then show a snapshot in the 210th steps. This reason is the same reason as a point though it seems even with this case as well as a case like a point that there are many agents on the stairs side. And, as for a walk, what is being done smoothly because the confrontation way of 2 layers is formed in the stairs and the horizontal deck is understood as for this case as well. When two simulation examples are compared, a difference isn't seen except for the difference in the number of agents by the difference in the flow volume. Here, we focus the difference in the change of the density in each Area.Fig.7 (b) and Fig.8 (b) corresponds to each of changes in the density by the area in case of the one for the flowing coefficients of 72, 36person/m • minute. Extreme the pedestrian density is taken, and the crowd density of the Area 2 exceeds/m^2 that are 2.0 people with the danger level of the crowd density in both cases. At the case of Fig.7 (b). Though the crowd density of Area 2 begins to exceed the density of 2.0person/m^2, the change of the Area 3 follows the change in the crowd density of Area2. At the case of Fig.8 (b). The crowd density of Are a2 show to action to raise and lower 2.0 and it decline crowd density 2 person/m^2, to steady condition as well as the case of low density flowing of third section.

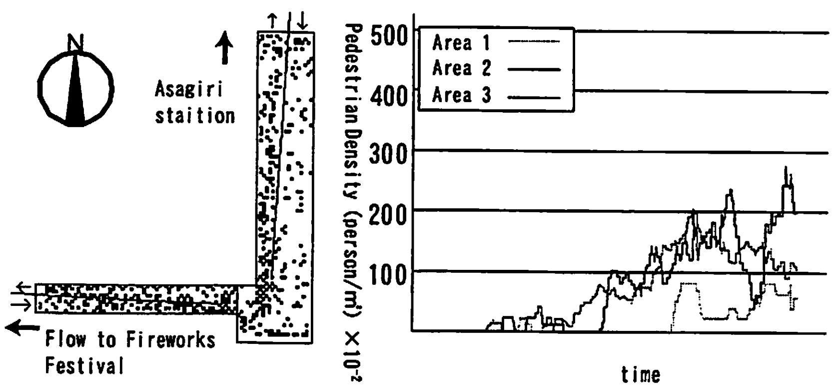

Fig. 8(a). Snapshots on Asagiri Pedestrian Overpass (b) Trajectories of Pedestrian Density (Flow volume 36 person/m*min, Standard queuing probability 33%)

Simulation Results

We try to simulate deference in crowd flowing by the difference in the number of queuing seen with haunt at the end of the south of the pedestrian overpass to see a firework. Flowing coefficient of the station side and the stairs side fixed 72 person/m • minute, and, stay probability was set at 44 %, then a state in 210 steps progress by simulation was shown in Fig.9 (a). It is no difference except for the number, which was compared with Fig.7. (a) of the preceding clause and that it is left behind isn't seen. Next, the change of the crowd density by the area at that time was shown in Fig.9 (b).It gets well over 2.0 person/m^2 in both areas as to the

danger level of the crowd density, in though a difference in the change the crowd density in Area 2 by the difference in stay number and Area3 is seen when we try to compare them with Fig.8 (a) of the result that this was simulated in the proceeding clause. Then, the similarly matter that it changes so that a change of the crowd density of Area 3 may follow a change of the crowd density of Area 2.

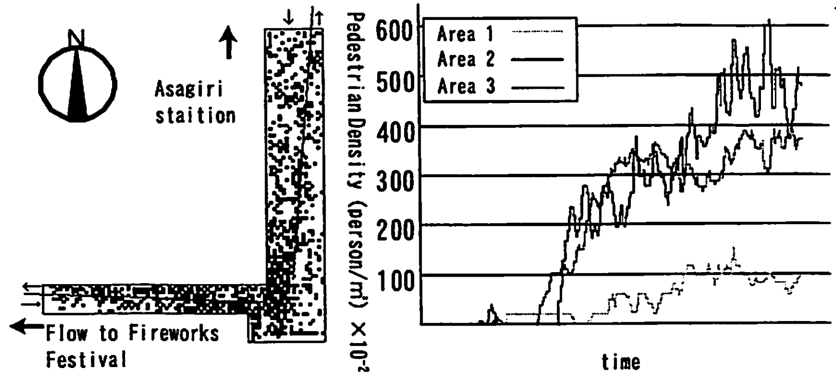

Fig. 9(a). Snapshot on Asagiri Pedestrian Overpass, (b) Trajectories of Pedestrian Density (Flow volume 72 person/m*min, Standard queuing probability 44%)

4.3 Consideration of the Results

It shows that (1) The change of the density in Area 3 followed the change of the density in Area 2. (2) The density in Area 3 does not go up when the density in Area 2 is comparatively low. So through following the similar discussion in the low-density simulation case, that the increase of the density in Area 2 causes the ones in Area 3. From the above results, we conclude that the collision of the flow from both directions in Area 2 had spread in Area 3, and, that it caused Akashi overpass accident. It is a fact that Area 2 coincide with the place where falling down one upon another occurred.

5 Conclusion

Through comparing between the simulation results and the survey data, we have verified similar behavioral performance of the pedestrian flow in the low density case under the condition of a set of the devised rules. The results of the simulation in the high density case suggests that the collision of the flow from both directions from the station side and the stairs side triggered the increase of pedestrian density on the overpass and that it caused the accident. Moreover, we also verified the point where the simulation results show the collisions is very closer to the point triggered the actual 'falling down one upon another' accident. So, we can also conclude our model simulates the high density flow. This model is simulating an occurrence process of the accident under the 'confrontation flows hypothesis. At a later time, the official fact-finding committee has explained the occurrence process using a model by 'one-way flow's queuing', but it has never denied the existence of the confrontation flows (Akashi City Summer Festival Accident Fact-Finding Committee, 2002,1).

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Author Index