BEHAVIORS OF PEDESTRIAN GROUP OVERTAKING WHEELCHAIR USER

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ABSTRACT

Means of escape of transportation facilities should be effective for evacuees including disabled persons. It is, therefore, important to develop methods for evaluating the effectiveness of means of escape for such persons, to maintain evacuation safety. For the purpose of developing such methods, we carried out a series of experiments to investigate the behavior of pedestrians and a wheelchair user. In all the experiments, thirty pedestrians and one wheelchair user had moved in a mock-up corridor, width of which was changed. The influences of the wheelchair user on the behaviors of pedestrians were analyzed based on the experiments. A numerical simulation model for normal movement of pedestrian group overtaking a wheelchair user has been developed. This model consists of simplified cognitive cycle and simple rules on behavior in relation to the distance to a wheelchair. It has been found that the model can well describe the phenomena observed through the experiments.

INTRODUCTION

Means of safe evacuation is still very important for ships even though ships have become safer, and various studies on evaluation and modeling of means of escape in ships have been conducted [1], and guidelines has been developed [2]. Ships shall also provide safety for disabled persons in their normal use and emergency occasions [3]. Therefore, safe evacuation measures for disabled persons from transportation facilities including ships should be ensured. A project has been started to develop methods to evaluate the effectiveness of means to escape in transportation facilities taking into account the existence of disabled persons. Aim of this study is to obtain data of behaviors of pedestrians and a wheelchair user in basic evacuation conditions and to develop models to simulate cases where pedestrians and wheelchair users escape together in transportation facilities for use in such evaluation.

EXPERIMENTS

We conducted experiments on the movement of pedestrians and a wheelchair user using 30 pedestrians (27 males and 3 females of collage students) and one wheelchair user, who wore colored helmets for identification purpose and moved together in a corridor mock-up of 15 m in length, as shown in Figure 1. The movement of them was recorded by a video camera set at about 30 m high above the corridor. The video images were compensated by the "Affine transformation". A position of a pedestrian was determined by the position of the pedestrian's helmet on the image data. Figure 2 shows an example of the image data. The details of the experiments have been reported in a journal of Japan Institute of Navigation [4].

The wheelchair was an electrical operation type and capable of keeping its traveling speed. The conditions of the experiments were shown in Table 1. The width of the corridor was fixed to 2 m, 3 m or 5 m. In cases where the width was 5 m, a doorway of 2m or 3m opening width was put in the middle of the corridor. The initial density of the pedestrians was 2, 3 or 4 persons/m^2. The wheelchair was (1) electrically driven by the user (speed at 0.8 m/s), (2) manually propelled by hands of the user, (3) pushed by an attendant, or (4) stayed. The speed of the wheelchair in case of (2) and (3) was kept in 0.8 m/s as far as possible. Psychology of pedestrian group was (1) kindness to the wheelchair user, or (2) competitiveness among the pedestrians. The wheelchair traveled in the center of the width of the corridor. The walking speed of the front row of the pedestrians was 1.5 m/s at the start.

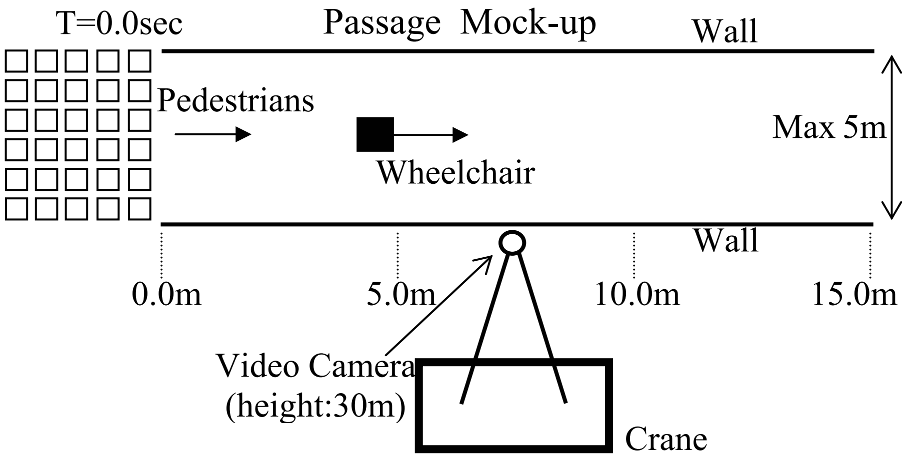

Figure 1 Outline of experiments

Figure 2 Example of image data from video pictures

WALKING SPEED OF PEDESTRIAN GROUP

In general, behaviors of evacuees are dominated by "group psychology" and we have been developing the evacuation simulation programs based on group psychology. The movements of pedestrians measured through the experiments were analyzed to obtain models for describing behaviors of the pedestrians. The speed of pedestrians (hereafter mentioned as "pedestrian group speed") in relation to the relative position to a wheelchair user was calculated by averaging the pedestrians walking speed at each relative position. It was observed that behaviors of both the wheelchair user and the pedestrians influenced each other, while both basically tended to keep their speed, and once changed the speed they tended to recover their speed to that of original.

Table 1 Condition of the experiments

Experiment No.	19	20	21	22	23	24	25	26	27	29
Wheelchair Condition	S	S	S	Mo	Mo	Mo	Mp	Ca	Mo	Mo
Pedestrian initial density (p/m^2)	2	3	4	4	3	2	3	3	3	3
Metal state of pedestrians	-	-	-	-	-	-	-	-	-	K
Corridor width (m)	3	3	3	3	3	3	3	3	3	3
Doorway width (m)	-	-	-	-	-	-	-	-	-	-

30	31	32	33	34	35	36	37	38	39	40	41	42	43	45
Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	S	Mo	Mo	Mo	Mp	Ca	Mo
3	2	2	2	2	3	3	3	3	3	2	4	3	3	3
M	K	M	C	NC	C	NC	-	-	-	-	-	-	-	K
3	3	3	3	3	3	3	3	2	2	2	2	2	2	2
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	S	Mo	Mo	Mo	Mo
3	3	3	4	3	3	3	3	3	3	3	3	3	3	3
M	C	NC	Mp	-	-	-	-	-	-	-	-	K	M	C
2	2	2	2	2	5	5	5	5	5	3	3	3	3	3
-	-	-	-	-	-	2	2	3	3	-	-	-	-	-

Wheelchair conditions: S: Stayed, Mo: Motorized, Mp: Manually propelled, Ca: Controlled by an attendant

Mental states: K: Kind, M: Mean, C: Competitive, UC: Non-competitive, Mp: Mean to push over, -: not specified

Figure 3 shows the pedestrian group speed in cases that the speed was lower. The abscissa and ordinate denote the relative position to the wheelchair and the pedestrian group speed, respectively. The gray thick line indicates the average of the pedestrian group speed through the experiments except cases trough 52 to 55. When the wheelchair stayed, the pedestrian group speed declined remarkably when pedestrians overtook the wheelchair. When the wheelchair propelled by the hands, the pedestrian group speed became slower than one in the case where the wheelchair was driven by motor. This implies that the pedestrian group speed is affected not only by the speed of the wheelchair but also by the fluctuation of the speed of the wheelchair. On the other hand, it was also observed that the reduced pedestrian group speed recovered to the initial speed or close to it after they overtook the wheelchair in all the experiments.

Figure 4 shows the pedestrian group speed in various group psychological conditions. The gray thick line is the average of the pedestrian group speed through the experiments except cases trough 52 to 55. When the pedestrians had competitive spirits or mean mental state, the pedestrian group speed was faster than that in the other mental conditions. On the other side when the pedestrians had no-competitive spirits or kind mental state, the pedestrian group speed was slower than that in the other psychological conditions. However, the speed was recovered almost to the initial speed after overtaking.

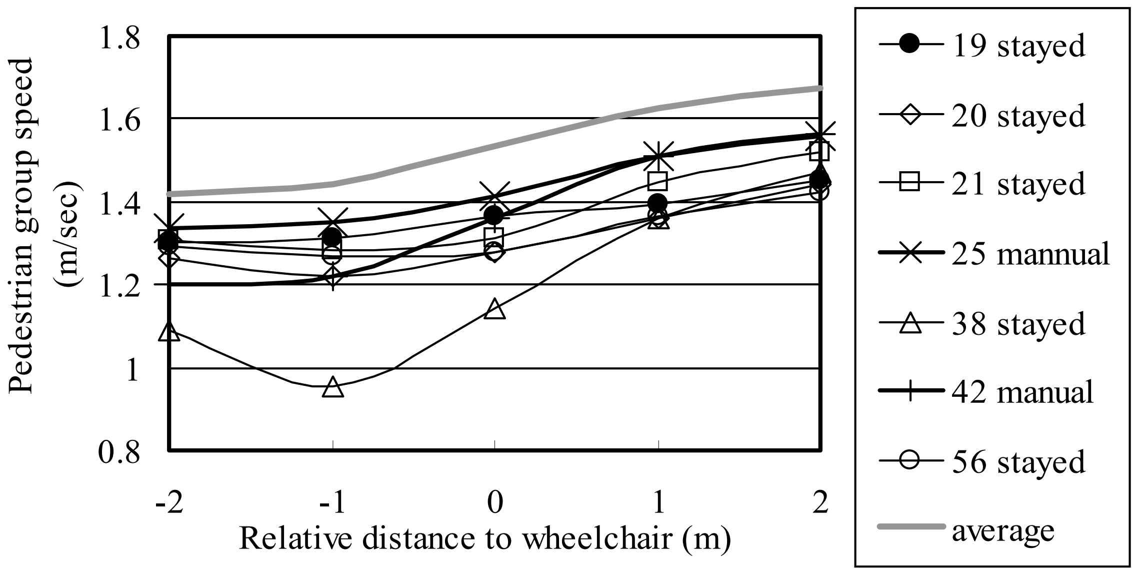

Figure 3 Pedestrian group speed in relation to wheelchair conditions

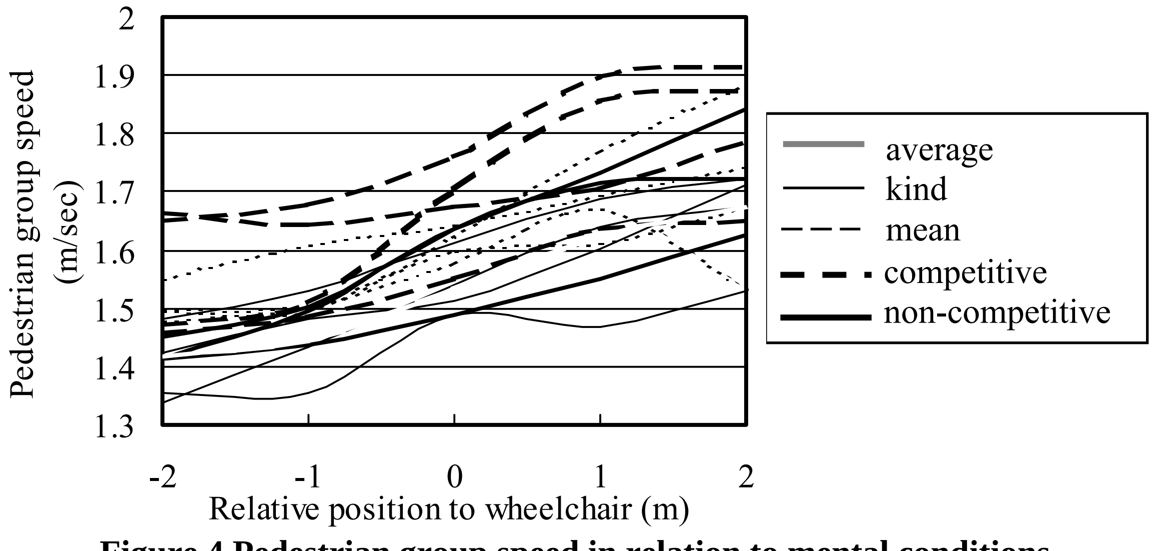

Figure 4 Pedestrian group speed in relation to mental conditions

BEHAVIOR AT DOORWAY

A doorway was set in the corridor on experiment 52 to 55. In these cases, the walking speed of some pedestrians, who went through the doorway together with or just after the wheelchair user, dropped at the doorway. Walking speed of several pedestrians dropped to 0.5 m/s in the cases where the doorway width was 2 m. In case where the doorway width was 3 m, walking speed of some pedestrians dropped to 1.0 m/s. The pedestrian group speed recovered to the initial walking speed of 1.5 m/s after overtaking the wheelchair user.

Figure 5 expressed the flow rate (persons/sec.) at the doorway. The abscissa denotes the ordinal number of pedestrian passing through the doorway. Outlined marks indicate the wheelchair user. In the cases of the 3 m doorway width, the average of their flow rate was 7 persons/sec. It means that the wheelchair user did not make significant influence to the flow rate. On the other side, the cases of the 2 m doorway width, the flow rate declined, and its value became 1 to 2 persons/sec. Therefore, it can be said that a wheelchair user seems to correspond to 2 or 3 pedestrians in regard to flow rate at doorway.

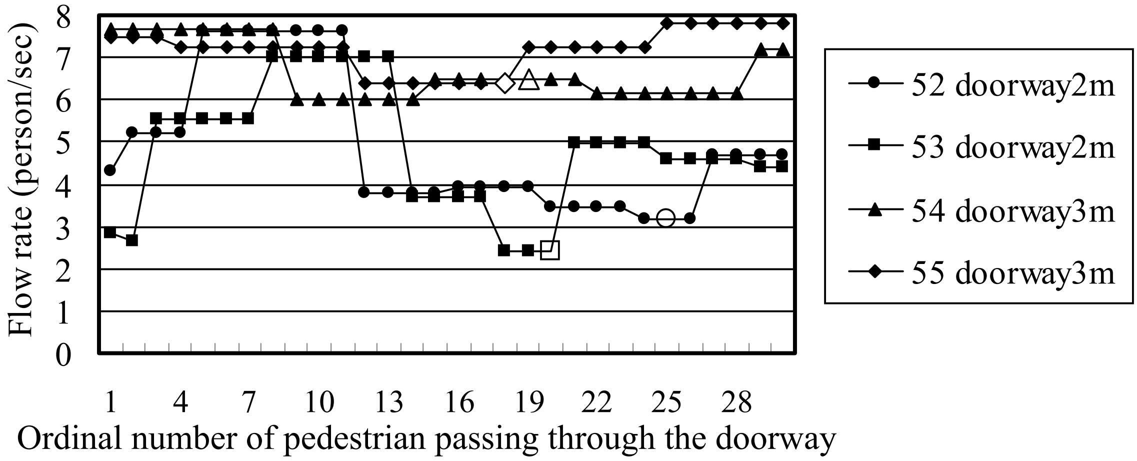

Figure 5 Flow rate at doorways

WALKING MODEL FOR OVERTAKING WHEELCHAIR USER

We investigated the behavior of the pedestrians who overtook the wheelchair user and identified 5 rules that explained features of the pedestrians' behaviors. The details of the model have been presented in a journal of Japan Institute of Navigation [5].

Rule 1. Rule for dividing walking zone by selections

The walking zone was divided into four sections, as shown in Figure 6 and defined as follows, in relation to the distance between pedestrians and a wheelchair:

Approach section is the section from the up-stream to the place where pedestrians start changing the course for avoiding a wheelchair;

Course change section is the section where pedestrians are changing the course;

Overtaking section is the section from the end of changing course until completion of overtaking a wheelchair; and

Post-Overtaking section is the section after overtaking a wheelchair and far down stream where pedestrians return to the original course and continue walking.

It was supposed that a pedestrian's action pattern in each section would defer from that in the other sections.

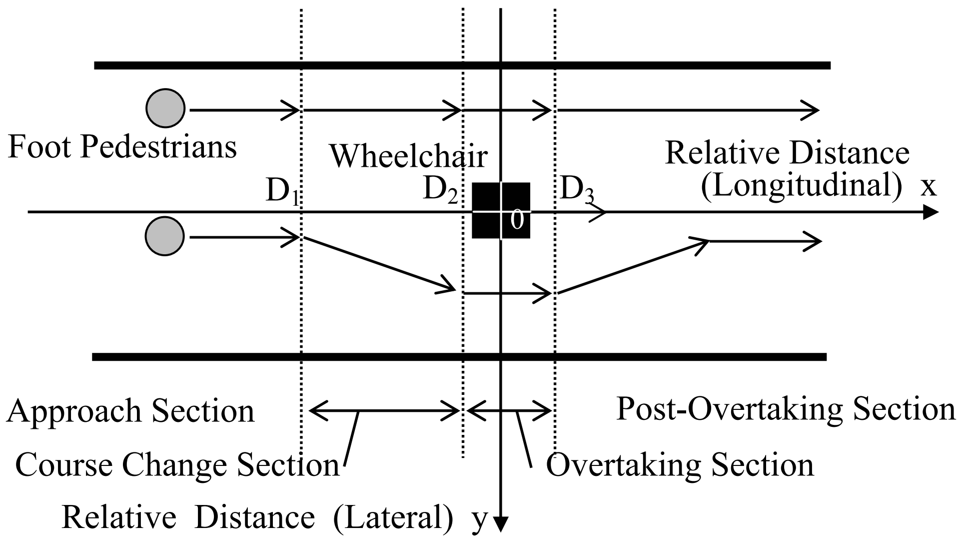

Figure 6 Sections of the walking model overtaking wheelchair user

Rule 2. Course change rule

On the occasion of overtaking a wheelchair, a course change is required. Before coming to the position of wheelchair, pedestrians start changing their course of walking and complete it before go into the section of overtaking. When they are in right-hand side to the center of a wheelchair, they change their courses rightward. When they are in left-hand side, they do leftward.

Rule 3. Speed adjustment rule

The pedestrian, who acts group behavior, adjust their speed as shown in Figure 7 in relation to the distance with other pedestrians. It would assume that there is a specific front-back distance (comfortable distance) between two pedestrians by which pedestrians feel comfortable for walking. Pedestrians slow down when come close to the other and try to keep the comfortable distance, and if the distance becomes longer than the comfortable distance, they accelerate. The comfortable distance has a band. In addition, the top speed can be defined as shown in Figure 8 in relation to distance with a pedestrian in front. This simplifies the situation that walking speed is specified in relation to the pedestrian's density.

Rule 4. Avoiding action rule

The rule for pedestrians to avoid the collision with other pedestrians is as follows.

Figures 7, 8 and 9 show the avoiding action rules about the advance direction corresponding to the position of the nearest pedestrian. According to the rules above, speed is adjusted to keep the comfortable distance forward and backward.

Moreover, Figure 10 shows the avoiding action rules about the right-and-left direction corresponding to the nearest pedestrian's position. The pedestrian’s walking speed is adjusted to keep more than comfortable distance about the right-and-left direction by these rules. In addition, since it would be difficult to obtain information about pedestrians at the back, other pedestrians who are at the back position more than θ_1 is presupposed not to affect the speed of the pedestrian concerned.

Rule 5. Cognitive activity cycle

The pedestrian performs the cycle of cognitive activity, which consists of four stages as shown in Figure 11 and continuously repeats the cycle. Above-mentioned rules 1 to 3 are carried out at the stage of **Expect** and rule 4 applies at the stage of **Modify**.

Expect: The pedestrian speed is temporally determined in relation to the intention chosen in respect to the relative distance with other pedestrians. Intentions are classified into 6 types, i.e., "Keep Velocity", "Avoid Wheelchair", "Accelerate", "Stop", "Keep Comfortable Distance" and "Recover Original Course".

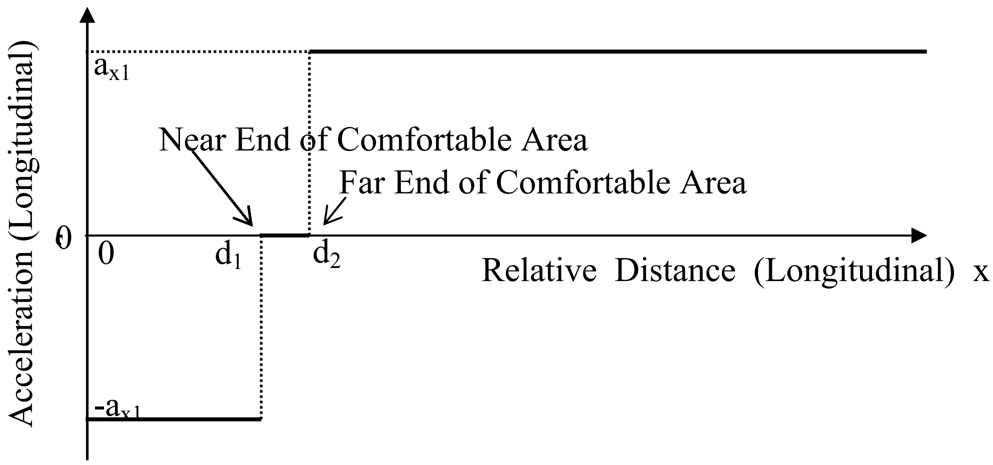

Figure 7 Speed adjustment according to relative distance to other pedestrians

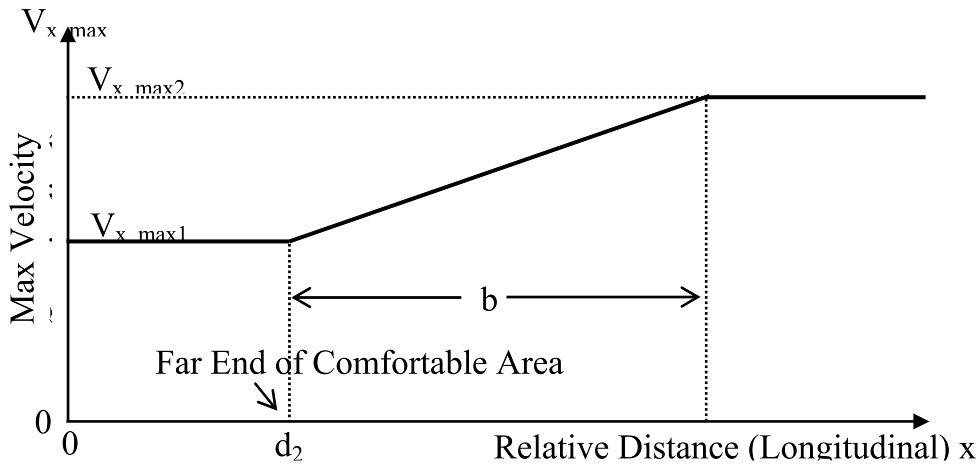

Figure 8 Maximum speed according to a distance

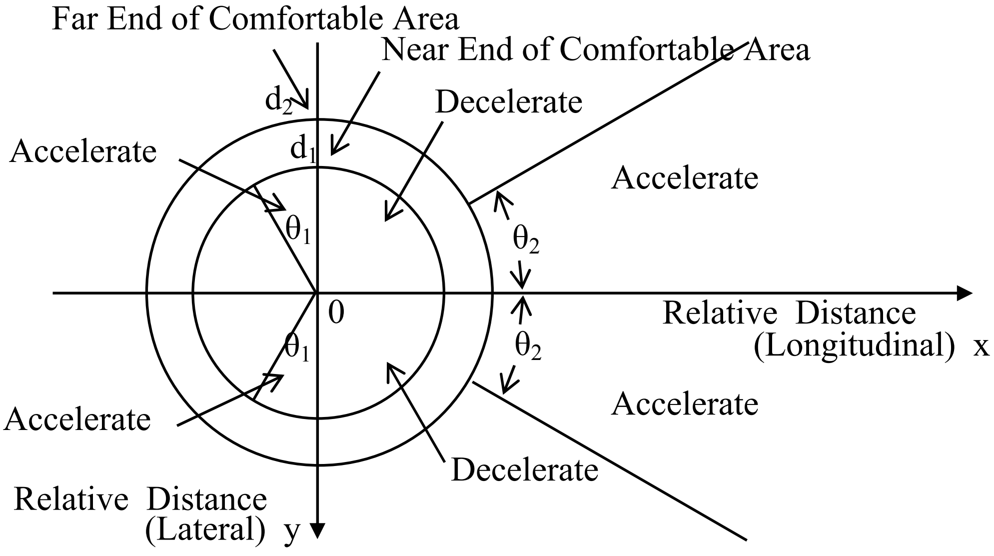

Figure 9 Avoiding action rules forward and backward

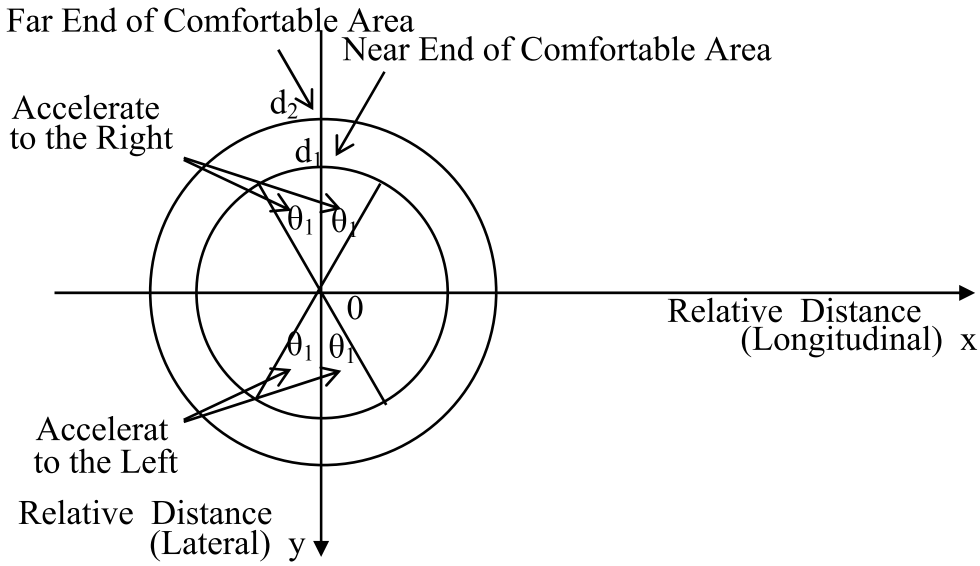

Figure 10 Avoiding action rules in the right-and-left direction

Estimate: Based on the wheelchair user and the other pedestrians' speed and positions, the pedestrian estimates their future positions after a certain time. In the numerical simulation, the pedestrian's future position is temporarily estimated based on the speed set at the stage of expect.

Modify: Necessary modification is carried out by the avoiding action rule in right relationship between the own expected future position and other objects' ones that are obtained at **Estimate** stage.

Execute: The pedestrian actually moves at the speed finally determined.

Table 2 shows the relation between the sections and the types of intention. In the stage of Expect, the pedestrians of succession in a group adopt an intention to maintain comfortable distance with a front pedestrian. Thereby, group behavior is realized.

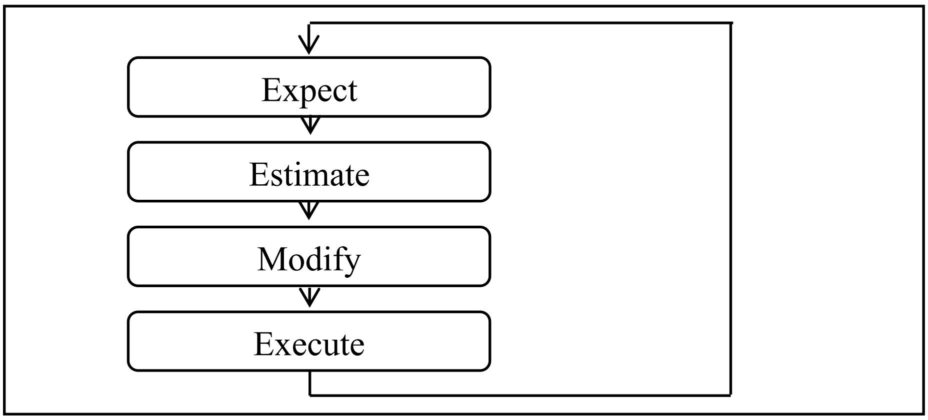

Figure 11 Cognitive activity cycle

Table 2 Relation between sections and types of intention

		Approach Section	Course Change Section	Overtaking Section	Post-Overtaking Section
Longi-tudinal	Top	Keep Velocity	Accelerate	Accelerate	Keep Velocity
	Following	Keep Comfortable Distance			
Lateral		Stop	Avoid Wheelchair	Stop	Recover Original Course

NUMERICAL SIMULATION

The numerical simulation program, which used the model of the preceding chapter, was developed. Then, numerical simulations were performed and the results were compared with experimental results of numbers 22 to 24 and 39 to 41.

The developed simulation technique is a multi-agent type, in which each pedestrian obtains information around it and acts upon its decision based on that information. Table 3 shows values of the parameters used in the numerical simulations, which could not be measured in the experiments. As it is thought that pedestrians in a group pay attention to the circumference, θ_1 would be rather high in realty. In addition, except two parameters Vx_max_1 and Vx_max_2, the common parameter values were used in all simulations. Figure 12 (a) shows the experimental result in the case of 3 m width corridor and Figure 12 (b) shows a simulation result in the same conditions. In both Figures "0" on the abscissa indicates the position of the wheelchair, and pedestrians' relative positions to the wheelchair are plotted. In these figures, the right direction is their advance direction. Figure 12 (a) and (b) have similarity and qualitatively good agreement. Figures 12 (c) to (e) show the average differences of every pedestrian's position between the experiments results and the simulation results. In these figures, when the simulated values are larger than the experimental ones, the values are plotted in the plus-direction. The ordinates are lapse time. The difference of lateral direction (right-and-left direction) is plotted in plus-direction, as the outer direction from the wheelchair position is plus-direction in both right and left. The maximum value in advance direction is 0.21 m and that in lateral direction is 0.09 m. They are enough small and have coincidence quantitatively. The presentation of the results of the 2 m width corridor cases is omitted from this paper due to the limited space of the paper. However, also in these cases, there is a good coincidence between the experiments and the numerical simulations quantitatively.

Table 3 Conditions of numerical simulations

Simulation Interval	0.1 sec
Estimation	1 second ahead
Section (Figure 6)	D_1 = 1.5 m, D_2 = 0.0 m, D_3 = -1.0 m
Comfortable Area (Figure 7)	d_1 = 0.5 m, d_2 = 0.6 m
Max Acceleration (Longitudinal) (Figure 7)	a_{x1} = 1.0 m/s^2
Max Velocity (Longitudinal) (Figure 8)	b = 1.0 m Vx_max_1 & Vx_max_2: Adjust Every Simulation
Avoid Other Person (Figure 9)	$\theta_1 = \theta_2 = 30°$
Max Velocity (Lateral)	0.3 m/s
Max Acceleration (Lateral)	0.5 m/s^2

In the simulations of 2 m width cases and 3 m width ones, the common parameter values were used except for two parameters of maximum speed. The distribution of these two parameters is shown in Figure 13. In this figure, Vx_max_1 of 2 m width case is smaller than that in 3 m width case. It can be explained that pedestrians feel more oppression against the pedestrian in front in the same distance, when they move in a narrower corridor and also that a tendency that the smaller pedestrian density results in the larger their walking speeds.

The value of Vx_max_2 is comparatively in agreement in both corridor widths. The reason would be that Vx_max_2 is restricted to the maximum walking speed.

This simulation program is able to predict the results of experiments in a good quantitative coincidence by adjusting only 2 parameters. Therefore, it is thought that this walking model for overtaking a wheelchair user is reasonable.

CONCLUSION

A series of experiments were conducted where a wheelchair user and 30 pedestrians escaped through a corridor mock-up, and it was found that their behavior influenced each other in relation to the physical conditions in the route and wheelchair and psychological condition of the pedestrians. The cases where a doorway existed, the flow rate at the doorway declined. On the condition that 5 m width corridor and 2 m width doorway and wheelchair user moving speed is half to pedestrians' one, the flow rate at the doorway declined in 1 to 2 persons/sec. In this condition a wheelchair user seemed to correspond to 2 or 3 pedestrians at the doorway.

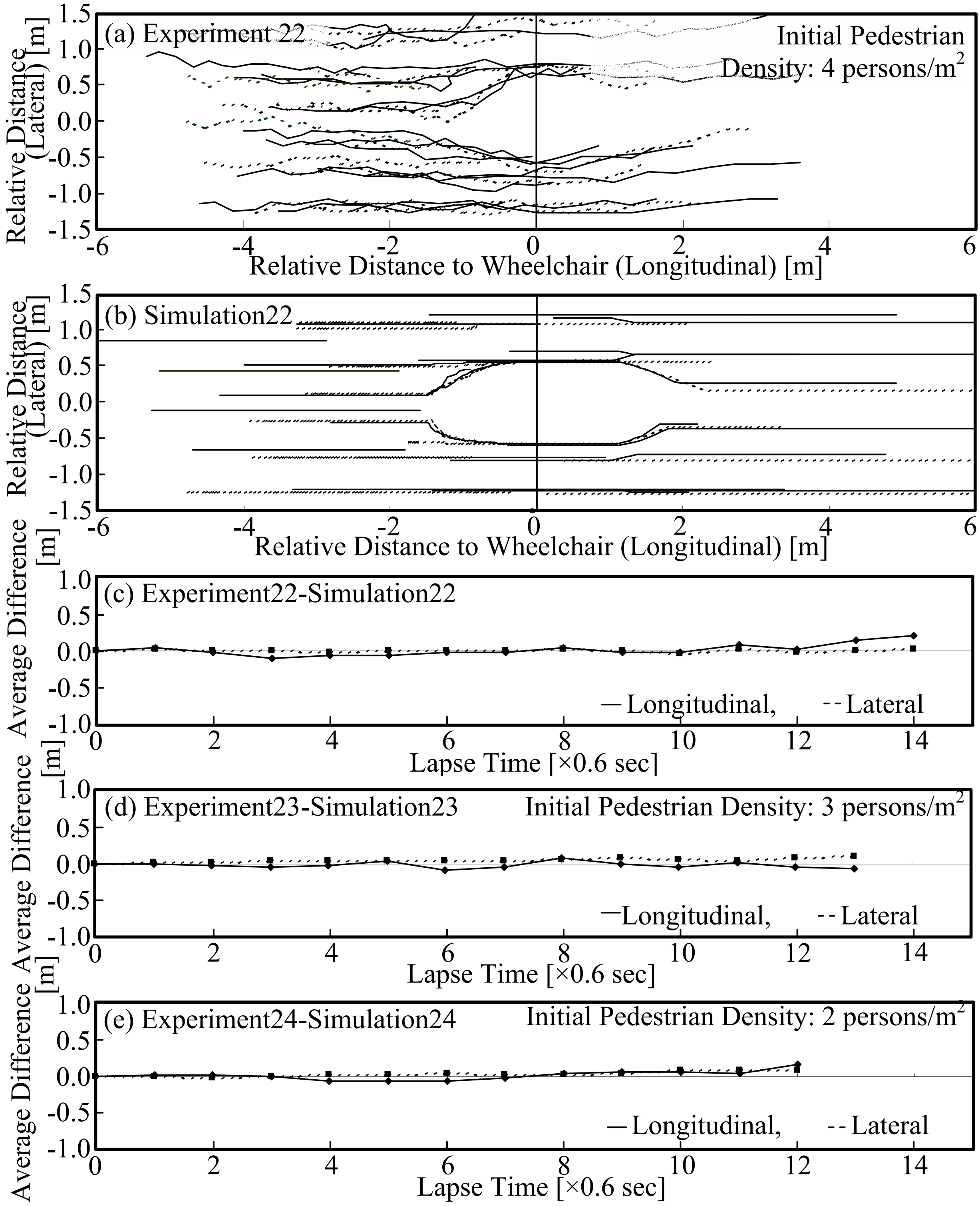

Figure 12 Experiments and calculations results comparison

We developed a walking model describing behavior of pedestrians when overtaking a wheelchair user in a corridor. The model uses simple cognitive cycle and simple behavior rules in relation to the distance to the wheelchair. A simulation program was developed based on the model, and reproduced well the phenomena obtained through the experiments. This validated the usefulness of the model and the simulation. Thus, this modeling approach can be used for evaluation of effectiveness of means of escape in transportation facilities.

It is important for passenger ships to maintain the safety of disabled persons, in particular, in the case of evacuation. Future evacuation analyses should be applicable to various situations including existence of disabled passengers and crew.

Models for movement of pedestrian groups and wheelchair users should be developed for various situations, e.g., in stairways, evacuation using lifts, etc. We have been in charge of such development based on experimental studies. This study is one of the steps toward the goal.

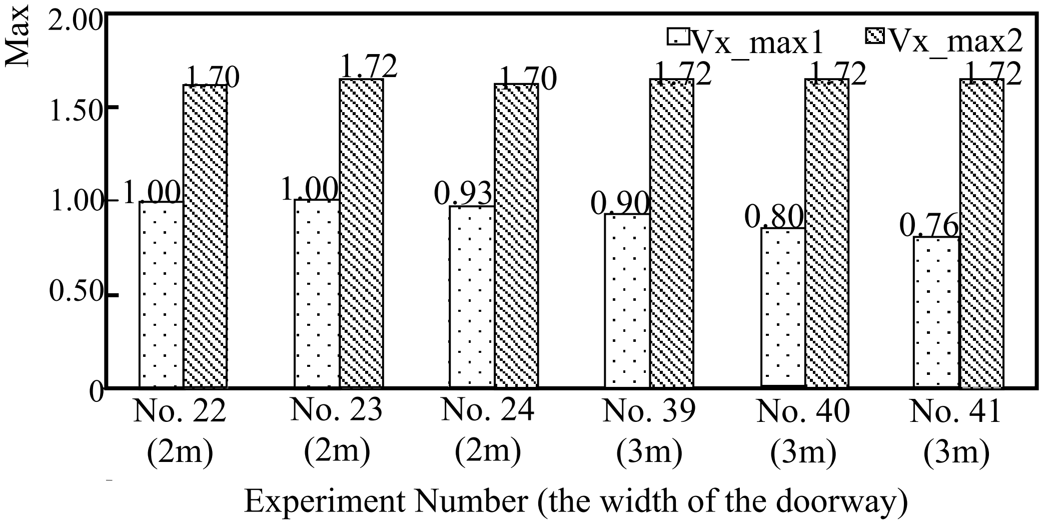

Figure 13 Parameter comparisons

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