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Office Layout Plan Evaluation System using Evacuation Simulation with Communication among Agents

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***Abstract*— In this paper, we propose an office layout plan evaluation system using evacuation simulation with communication among agents. The proposed system evaluates office layout plans generated by the office layout support system using genetic algorithm. This office layout support system can generate layout plans which satisfy some conditions given by users. However, the flow of office workers can not considered in the system. In the proposed system, the office layout plan generated by the office layout support system using genetic algorithm and the conditions for agents are given, and then the agents move under the conditions. Based on the behavior of agents, the evaluation on the maximum time for escape, average speed, the number of agents who could not reach entrance and so on are carried out. We carried out a series of computer experiments in order to demonstrate the effectiveness of the proposed system and confirmed that the proposed system can evaluate layout plans.**

I. Introduction

When we consider how fixture and furniture such as desks and shelves are arranged to the limited space such as an office and a laboratory, we arrange various kinds of furniture virtually on a paper. Moreover, the software for an office layout is also put on the market, and we can also think arranging furniture virtually on a screen using it. However, it is difficult to consider the layout plans which satisfy various conditions such as a size of room, the number of the furniture to be arranged and so on.

As the system which can generate layout plans which satisfy the conditions given by users automatically, the interior design layout support system[1] has been proposed. However, in the system, each desk is arranged individually, so the desks are sometimes arranged in disorder. As a result, it is difficult to generate a practical layout plan. In ref.[2], the interior design layout support system using evaluation agents has been proposed, however, the system sometimes generate layout plans which do not satisfy all conditions given by users.

Recently, we have proposed some office layout support systems using genetic algorithm [3][4]. In these systems, some conditions such as size and form of room, size and the number of desks are given by users, some layout plans which satisfy the conditions are generated by genetic algorithm. However, the flow of office workers can not considered in the system.

On the other hand, we have proposed the office layout evaluation system for normal use and emergency by multiagent[5]. This system can evaluate office layout plans generated by the office layout support system using genetic algorithm[3][4]. And the flow of office workers can be considered in the system. However, in this system, communication among agents can not be considered.

In this paper, we propose an office layout plan evaluation system using evacuation simulation with communication among agents. In the proposed system, the office layout plan generated by the office layout support system using genetic algorithm[3][4] and the conditions for agents are given, and then the agents move under the conditions. Based on the behavior of agents, the evaluation on the maximum time for escape, average speed, the number of agents who could not reach entrance and so on are carried out.

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II. Office Layout Plan Evaluation System using Evacuation Simulation with Communication among Agents

Here, we explain the proposed office layout plan evaluation system using evacuation simulation with communication among agents. This system evaluates office layout plans generated by the office layout support system using genetic algorithm[3][4]. In the proposed system, the agents move to the entrance, and based on the behavior of agents, the evaluation for the time, distance, speed for escape and so on are carried out.

A. Initial Setting

(1) Initial Position of Agents

Each agent is assigned in front of own desk (Fig.1(a)) or random place (Fig.1(b)).

(2) Impassable Space

In the proposed system, impassable spaces are generated randomly. The number of the impassable spaces N_d is determined from 0 to N_d^{max} randomly. Here, N_d^{max} is given by

$$N_d^{max} = \lceil C_d S_f \rceil \qquad (1)$$

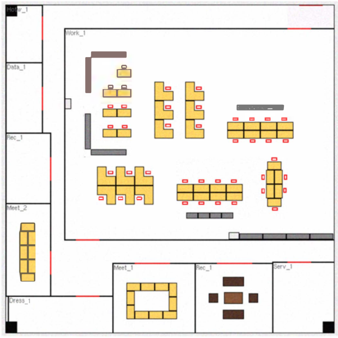
where $S_f(m^2)$ is the floor size, and C_d is the coefficient. The positions of N_d impassable spaces are determined randomly, and each area is set as the square whose length of each side takes 1$\sim$3(m).

Figure 2 shows an example of impassable spaces.

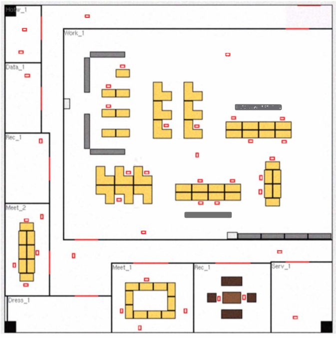
B. Evacuation Simulation

The action of agents can be divided into the following three cases.

(1) Recognition of Environment
(2) Decision of Escape Route
(3) Communication among Agents



(a)



(b)

Fig. 1. Initial Position of Agents.

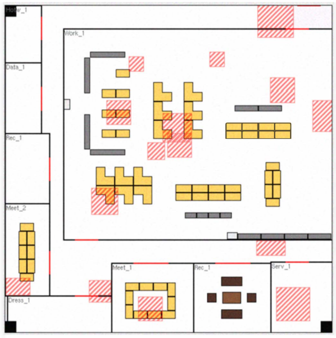


Fig. 2. Impassable Spaces.

(1) Agent Speed

The speed of each agent is determined based on the population density. In the proposed system, based on the population density, the following three cases are considered.

(a) Normal Area ($D_i < 1.5$)
(b) Crowd Walking Area ($1.5 \leq D_i < 6.0$)
(c) Difficulty Walking Area ($6.0 \leq D_i$)

where D_i is the population density around the agent i.

The speed of the agent i, ν_i is given by

$$\nu_i = \left(\frac{1.0}{1.0 + \exp((D_i - a)/b)} \right) \nu_0 \qquad (2)$$

where ν_0 is the speed in the normal area, a and b are the coefficients. In the proposed system, ν_0 is set to $1.4(m/s)$, a is set to 3.5, and b is set to 0.35.

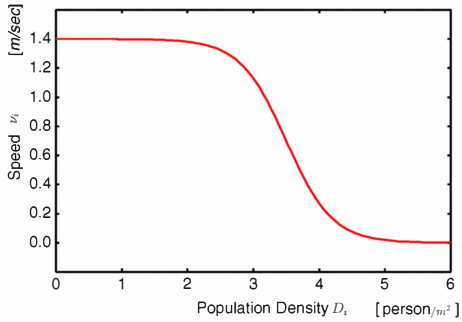


Fig. 3. Relation between Population Density and Agent Speed.

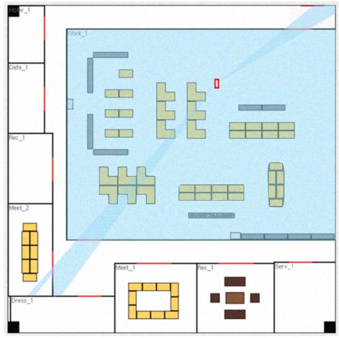


Fig. 4. An example of View of Agent.

Figure 3 shows the relation between the population density and speed of the agent.

(2) Recognition of Environment

In the proposed system, each agent can see 360-degree views, and can obtain the information on impassable spaces and crowd/difficulty walking areas. Figure 4 shows an example of view of agent. In this figure, red rectangle shows agent, and blue area show the view of the agent.

(3) Decision of Escape Route

(3-1) Information

In this system, agents decide own escape route based on the information about (a) office layout, (b) impassable spaces and (c) crowd/difficulty walking area.

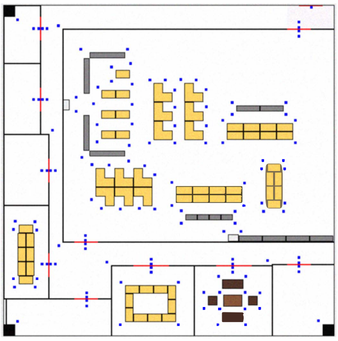
(a) Office Layout

In the proposed system, each agent is an office worker. So, each agent knows the office layout such as the position of room and furniture.

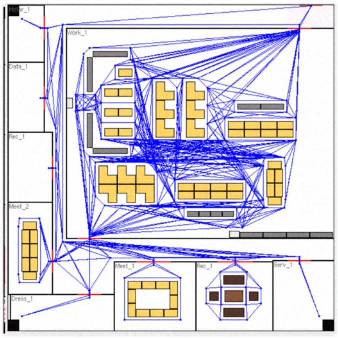
(b) Impassable Spaces

In the proposed system, each agent gets the information on the impassable space when the agent see it or hear it from the other agent.

In this research, the degree of importance for the information on the impassable spaces $I^{ip}(0 \leq I^{ip} \leq 1)$ is defined. If I^{ip} is larger than the threshold θ_I, the agent i emphasize the information on the impassable space p. The degree of importance for the information on the impassable space p, I^{ip} is set to 0 at the beginning of the simulation, and it is



(a) Setting of Nodes



(b) Path Candidates

Fig. 5. An Example of Path Candidates.

updated as follows.

$$I^{ip} \leftarrow \begin{cases} f_I(I^{ip} + \Delta I_1), \\ \quad \text{when agent } i \text{ see impassable space } p \\ f_I(I^{ip} + \Delta I_2), \\ \quad \text{when agent } i \text{ hear the impassable space } p \end{cases} \tag{3}$$

where ΔI_1 and ΔI_2 ($\Delta I_2 < \theta_I < \Delta I_1$) are update value. $f_I(\cdot)$ is the function given by

$$f_I(u) = \begin{cases} u, & u < 1 \\ 1, & 1 \leq u. \end{cases} \tag{4}$$

(c) Crowd/Difficulty Walking Areas

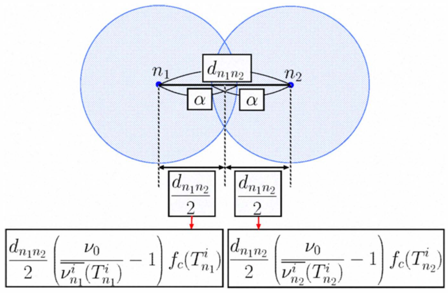
In the proposed system, each agent gets the information on the crowd/difficulty walking area when the agent sees it.

(3-2) Path Candidates

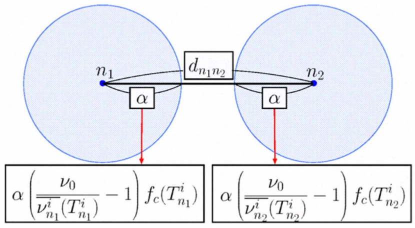
In the proposed system, nodes are set on the floor (Fig.5(a)), and path candidates are determined by the Dijkstra method[6] floor(Fig.5(b)).

(3-3) Route Decision

The agent decides own route to the entrance by the Dijkstra method considering the information on impassable spaces and crowded areas. The agent i uses the costs from node n_1 to n_2 ($d^i_{n_1 n_2}$) in the Dijkstra method.



(a) When $d_{n_1 n_2} \leq 2\alpha$



(b) When $2\alpha < d_{n_1 n_2}$

Fig. 6. Costs between Nodes.

$$d^i_{n_1 n_2} = \begin{cases} d_{n_1 n_2} + \dfrac{d_{n_1 n_2}}{2}\left(\dfrac{\nu_0}{\overline{\nu^i_{n_1}}(T^i_{n_1})} - 1\right) f_C(T^i_{n_1}) \\ \quad + \dfrac{d_{n_1 n_2}}{2}\left(\dfrac{\nu_0}{\overline{\nu^i_{n_2}}(T^i_{n_2})} - 1\right) f_C(T^i_{n_2}), \\ \hfill d_{n_1 n_2} \leq 2\alpha \\ d_{n_1 n_2} + \alpha\left(\dfrac{\nu_0}{\overline{\nu^i_{n_1}}(T^i_{n_1})} - 1\right) f_C(T^i_{n_1}) \\ \quad + \alpha\left(\dfrac{\nu_0}{\overline{\nu^i_{n_2}}(T^i_{n_2})} - 1\right) f_C(T^i_{n_2}), \\ \hfill 2\alpha < d_{n_1 n_2} \end{cases} \tag{5}$$

where $d_{n_1 n_2}$ is the distance between the node n_1 and the node n_2, α is a radius of the circle (see Fig.6), $\overline{\nu^i_{n_1}}(T^i_{n_1})$ is the average speed of agents in the circle whose center is the node n_1, and $\overline{\nu^i_{n_2}}(T^i_{n_2})$ is the average speed of agents in the circle whose center is the node n_2. If there is no agent in the circle, $\overline{\nu^i_{n_1}}(T^i_{n_1})$ and $\overline{\nu^i_{n_2}}(T^i_{n_2})$ are set to $\nu_0 (m/s)$ (speed in the normal area). $T^i_{n_1}$ (or $T^i_{n_2}$) shows the number of steps from the time when the agent i sees the node n_1 (or n_2).

(4) Communication among Agents

In the proposed system, agents send and receive the message on impassable spaces.

(4-1) Sending of Information The agent i can send a message when the other agents are in its view. The agent i can send a message on the impassable spaces whose degree of importance I^{ip} is larger than the threshold θ_I. The contents of the message (the impassable s_i) is determined by

$$s_i = \underset{C^{ip}}{\operatorname{argmax}}(w_{I1}I^{ip} + w_P P^p + w_{D1} f_{D1}(D_1^{ip}) \\ + w_{R1} f_{R_1}(R_1^{ip}) + w_S f_S(S^{ip})) \quad (6)$$

where w_{I1}, w_P, w_{D1}, w_{R1} and w_S are coefficients which satisfy

$$w_{I1} + w_P + w_{D1} + w_{R1} + w_S = 1. \quad (7)$$

In Eq.(6), P^p shows the influence of the impassable space p to escape routes (0 or 1), D_1^{ip} is the distance from the agent i to the impassable space p. $f_{D1}(\cdot)$ is given by

$$f_{D1}(u) = \frac{1}{1 + \exp((u - a_{D1})/\varepsilon_{D1})} \quad (8)$$

where a_{D1} and ε_{D1} are coefficients. R_1^{ip} is the number of steps from the agent i receives the information on the impassable space p or sees the impassable space p. $f_{R1}(\cdot)$ is given by

$$f_{R1}(u) = \begin{cases} 1, & u < \theta_{R1} \\ 1 - \dfrac{(u - \theta_{R1})(1 - b_R)}{\theta_{R2} - \theta_{R1}}, & \theta_{R1} \leq u \leq \theta_{R2} \\ b_R, & \theta_{R2} < u \end{cases} \quad (9)$$

where b_R is the constant ($0 < b_R < 1$), and θ_{R1} and θ_{R2} ($0 < \theta_{R1} < \theta_{R2}$) are thresholds. S^{ip} is the number of steps from the agent i sends the information on the impassable space p. $f_S(\cdot)$ is given by

$$f_S(u) = \begin{cases} b_S, & u < \theta_{S1} \\ b_S + \dfrac{u - \theta_{S1}}{\theta_{S1} - \theta_{S2}}, & \theta_{S1} \leq u \leq \theta_{S2} \\ 1, & \theta_{S2} < u \end{cases} \quad (10)$$

where b_S is the constant ($0 < b_S < 1$), θ_{S1} and θ_{S2} ($0 < \theta_{S1} < \theta_{S2}$) are the thresholds.

(b) Whether Information is Sent or Not

In the proposed system, the agents send the information on the impassable space s_i with the probability p_i^{send}.

$$p_i^{send} = f_{se}(w_{I2}I^{is_i} + w_{D2} f_{D1}(D_1^{is_i}) \\ + w_{R2} f_{R1}(R_1^{is_i}) + w_{O1} f_{O1}(O_1^i)) \quad (11)$$

where w_{I2}, w_{D2}, w_{R2} and w_{O1} are coefficients which satisfy

$$w_{I2} + w_{D2} + w_{R2} + w_{O1} = 1. \quad (12)$$

In Eq.(11), I^{is_i} is the degree of importance to the impassable space s_i of the agent i, $D_1^{is_i}$ is the distance between the agent i and the impassable space s_i, $R_1^{is_i}$ is the number of steps from the agent i obtains the information on the impassable space s_i. O_1^i is the number of agents who are sending the message in the circle whose center is the agent i. $f_{O1}(\cdot)$ is given by

$$f_{O1}(u) = \begin{cases} 1 + \dfrac{u(1 - b_{O1})}{\theta_{O1}}, & u \leq \theta_{O1} \\ b_{O1}, & \theta_{O1} < u \end{cases} \quad (13)$$

where b_{O1} is the constant ($0 < b_{O_1} < 1$), and θ_{O1} ($0 < \theta_{O1}$) is the threshold. And, $f_{se}(\cdot)$ is given by

$$f_{se}(u) = \tanh(\varepsilon_{se} u) \quad (14)$$

where ε_{se} is the steepness parameter.

(c) Sending of Message

If the agent i decides to send the message in **(b)**, the agent i sends the message on the impassable message s_i during $T^i(N_{s_i}^{near})$ steps.

(4-2) Receiving of Information

In the proposed system, each agent can receive from only one agent at the same time. If there are plural agents who send message around the agent i, the agent i decides to receive the message from the nearest agent.

If the agent i does not send any message, and there are one and more agents who begin to send messages, the agent i begins to receive the message from the nearest agent who begins to send the message.

Even when the agent i is receiving the message from the agent j, if there is the agent k who begins to send a message near the agent i, the agent i has a possibility to begin to receive the message from the agent k. The agent i begins to receive the message from agent k when the following condition is satisfied.

$$f_{D2}(D_2^{ij}) + f_{R2}(R_2^{ij}) < f_{D2}(D_2^{ik}) \quad (15)$$

where D_2^{ij} is the distance between the agent i and the agent j, and D_2^{ik} is the distance between the agent i and the agent k. And, $f_{D2}(\cdot)$ is given by

$$f_{D2}(u) = \frac{1}{1 + \exp((u - a_{D2})/\varepsilon_{D2})} \quad (16)$$

where a_{D2} and ε_{D2} are the coefficients.

R_2^{ij} is the number of steps from the agent i receives the message from the agent j. $f_{R2}(\cdot)$ is given by

$$f_{R2}(u) = \tanh(\varepsilon_{R2} u) \quad (17)$$

where ε_{R2} is the steepness parameter.

The agent i can get the information when it receives the message from the agent j during $T^j(T_{s_j}^{near})$ steps with the following probability.

$$p_i^{receive} = f_{re}(w_{D3} f_{D3}(D_3^{ij}) + w_{O2} f_{O2}(O_2^i)) \quad (18)$$

where w_{D3} and w_{O2} are the coefficients which satisfy

$$w_{D3} + w_{O2} = 1. \quad (19)$$

In Eq.(18), D_3^{ij} is the average distance between the agent i and the agent j during $T^j(N_{s_j}^{near})$ steps. And $f_{D3}(\cdot)$ is given by

$$f_{D3}(u) = \frac{1}{1 + \exp((u - a_{D3})/\varepsilon_{D3})} \quad (20)$$

where a_{D3} and ε_{D3} are coefficients.

O_2^i is the average number of the agents in the circle whose center is the agent i and whose radius is $\gamma(m)$. And $f_{O2}(\cdot)$ is given by

$$f_{O2}(u) = \begin{cases} 1 - \dfrac{u(1-b_{O2})}{\theta_{O2}}, & u \le \theta_{O2} \\ b_{O2}, & \theta_{O2} < u \end{cases} \tag{21}$$

where b_{O2} is the constant ($0 < b_{O2} < 1$), and θ_{O2} ($0 < \theta_{O2}$) is the threshold. $f_{re}(\cdot)$ is given by

$$f_{re}(u) = \tanh(\varepsilon_{re} u) \tag{22}$$

where ε_{re} is the steepness parameter.

C. Evaluation by Agents

The following five items are evaluated based on the movement of agents.

(1) Time for Escape

(a) Average Time for Escape

In the proposed system, the evaluation value for the average time for escape $E_{ave-time}$ is calculated as follows.

$$E_{ave-time} = \frac{\sum_{k=1}^{N_{all}} T_k}{N_{all}} \tag{23}$$

where N_{all} is the number of agents who can reach the entrance, and T_k is the time for escape of the agent k.

(b) Maximum Time for Escape

The evaluation value for the maximum time for escape $E_{last-time}$ is calculated as follows.

$$E_{last-time} = \max_k T_k \tag{24}$$

(2) Average Distance for Escape

The evaluation value for the average distance for escape $E_{ave-dis}$ is calculated as follows.

$$E_{ave-dis} = \frac{\sum_{k=1}^{N_{all}} D_k}{N_{all}} \tag{25}$$

where D_k is the distance for escape of the agent k.

(3) Average Speed

The evaluation value for the average speed $E_{ave-speed}$ is calculated by

$$E_{ave-speed} = \frac{E_{ave-dis}}{E_{ave-time}} = \frac{\sum_{k=1}^{N_{all}} D_k}{\sum_{k=1}^{N_{all}} T_k}. \tag{26}$$

(4) The Number of Agents Who Could Not Reach Entrance

The number of agents who could not reach the entrance is used as the evaluation value $E_{failed-agent}$.

(5) Frequency of Crowd/Difficulty Walking Area

(a) Frequency of Crowd Walking Area

The evaluation value for the frequency of the crowd walking area $E_{slow-zone}$ is given by

$$E_{slow-zone} = \sum_{k=1}^{N_{all}} N_k^{slow} \tag{27}$$

where N_k^{slow} is the number of steps that the agent k in the crowd walking area.

(b) Frequency of Difficulty Walking Area

The evaluation value for the frequency of the difficult walking area $E_{stop-zone}$ is given by

$$E_{stop-zone} = \sum_{k=1}^{N_{all}} N_k^{stop} \tag{28}$$

where N_k^{stop} is the number of steps that the agent k in the difficulty walking area.

III. Computer Experiment Results

In this section, we show the computer experiment result to demonstrate the effectiveness of the proposed system. In this experiment, the layout plans shown in Fig.7 were used.

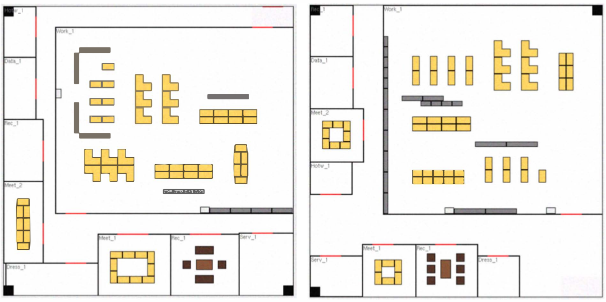
A. Effect of Communication

Table I shows the evaluation results of the proposed system. Here, we examined in the layout plan (a) in Fig.7. As shown Table I, in the proposed system (with communication), the average and maximum time for escape is shorter than the case in the system without communication among agents. Moreover, in the proposed system, the agents can obtain the information on the impassable spaces even when they do not see the impassable spaces directly and can select appropriate route, so only a few crowd/difficulty walking areas appeared.

B. Difference between Layout Plans

Table II shows the another evaluation results of the proposed system. Here, we examined in the layout plan (b) and (c) in Fig.7. From the result shown in Table II, we can say that the layout plan (b) is superior to the layout plan (c).

(a)



(b) (c)

Fig. 7. An example of Layout Plans.

IV. Conclusion

In this paper, we have proposed the office layout plan evaluation system using evacuation simulation with communication among agents. The proposed system evaluates office layout plans generated by the office layout support system using genetic algorithm. In the proposed system, the office layout plan generated by the office layout support system using genetic algorithm and the conditions for agents are given, and then the agents move under the conditions. Based on the behavior of agents, the evaluation on the maximum time for escape, average speed, the number of agents who could not reach entrance and so on are carried out. We carried out a series of computer experiments in order to demonstrate the effectiveness of the proposed system and confirmed that the proposed system can evaluate layout plans.

TABLE I

Evaluation (Effect of Communication).

	Initial Position	Trial No.	$E_{ave-time}$[sec]
with Communication	Own Seat	1	41.5
	Random	30	33.6
without Communication	Own Seat	1	66.0
	Random	30	39.7

	Initial Position	Trial No.	$E_{last-time}$[sec]
with Communication	Own Seat	1	63.0
	Random	30	57.9
without Communication	Own Seat	1	130.0
	Random	30	82.8

	Initial Position	Trial No.	$E_{ave-dis}[m]$
with Communication	Own Seat	1	41.3
	Random	30	38.6
without Communication	Own Seat	1	46.4
	Random	30	40.5

	Initial Position	Trial No.	$E_{ave-speed}[m/\text{sec}]$
with Communication	Own Seat	1	1.04
	Random	30	1.18
without Communication	Own Seat	1	0.86
	Random	30	1.12

	Initial Position	Trial No.	$E_{slow-zone}$[times]
with Communication	Own Seat	1	70
	Random	30	33
without Communication	Own Seat	1	1548
	Random	30	51

	Initial Position	Trial No.	$E_{stop-zone}$[times]
with Communication	Own Seat	1	0.00
	Random	30	0.00
without Communication	Own Seat	1	3.00
	Random	30	0.03

TABLE II

Evaluation (Difference between Layout Plans).

Layout Plan	Initial Position	Trial No.	$E_{ave-time}$[sec]
Layout Plan (b)	Own Seat	1	21.0
	Random	30	21.0
Layout Plan (c)	Own Seat	1	26.4
	Random	30	20.6

Layout Plan	Initial Position	Trial No.	$E_{last-time}$[sec]
Layout Plan (b)	Own Seat	1	35.0
	Random	30	34.6
Layout Plan (c)	Own Seat	1	43.0
	Random	30	37.7

Layout Plan	Initial Position	Trial No.	$E_{ave-dis}[m]$
Layout Plan (b)	Own Seat	1	18.2
	Random	30	22.6
Layout Plan (c)	Own Seat	1	22.8
	Random	30	24.0

Layout Plan	Initial Position	Trial No.	$E_{ave-speed}[m/\text{sec}]$
Layout Plan (b)	Own Seat	1	0.93
	Random	30	1.14
Layout Plan (c)	Own Seat	1	0.94
	Random	30	1.16

Layout Plan	Initial Position	Trial No.	$E_{slow-zone}$[times]
Layout Plan (b)	Own Seat	1	307.0
	Random	30	266.1
Layout Plan (c)	Own Seat	1	610.0
	Random	30	154.5

Layout Plan	Initial Position	Trial No.	$E_{stop-zone}$[times]
Layout Plan (b)	Own Seat	1	0.00
	Random	30	0.00
Layout Plan (c)	Own Seat	1	0.00
	Random	30	0.00

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