Developing A Spatial Assessment System of Moving Passengers' Stress in Railway Stations: A View of Distancing, Speed Fluctuation, and Interweaving

Yuki FUKUDA [a*] and Hitoshi IEDA [b]

[a] *Creative Research and Planning Co., Ltd, 1-20-22 Ebisu, Shibuya-ku, Tokyo 150-0013, Japan*
[b] *National Graduate Institute for Policy Studies, 7-22-1 Roppongi, Minato-ku, Tokyo 106-8677, Japan*
[a] *E-mail: y_fukuda@crp.co.jp*
[b] *E-mail: ieda@grips.ac.jp*

Abstract: Stations in urban areas of Japan have been heavily congested by commuters during rush hours. Railway companies are carrying out improvement work on station facilities to alleviate the congestion. However, because there are no design standards that take passengers' stress into consideration in Japan, there are cases where problems occur in the management and operation of station space, such as congestion on platforms and ticket gate floors, even at the new stations. In this study, focus on the stress on passengers (high density, speed reduction, and interweaving with other pedestrians), and develop a spatial assessment system of passengers' stress in railway stations. By using these stress indicators, it is possible to identify the problem areas in the station space, as well as at the specific locations such stairs and platforms more clearly.

Keywords: Railway stations, Pedestrian simulation, Moving passengers' stress, Pedestrian density, Speed reduction, Interweaving with others

1. INTRODUCTION

During the morning and evening rush hours at urban railway stations in japan, significant congestion high passenger demand occurs on platforms, concourses, ticket gates, etc. On the other hand, during off-peak hours, there are passengers with various attributes such as children, passengers with suitcase, and wheelchair users. Although there are not as many passengers as during the morning and evening rush hours, congestion and interweaving occur by the mixture of various attributes. Therefore, at urban railway stations in japan, congestion and interweaving occur throughout the day. This leads to the perception of the lacking of passenger comfort inside the railway station. One of the factors that cause such a situation is that detailed passenger flow characteristics cannot be taken into consideration at the space design stage of railway stations. Therefore, even if the station has just been opened or improved, passengers may be heavily congested on the platform or ticket gate floor, which may hinder the comfortable use space for passengers and cause significant problems in the management and operation of the station space. Therefore, it is necessary to assess the station space in consideration of passenger comfort and flow characteristics at the station spatial design stage.

Also, the importance of the station space being a comfortable space for passengers has been addressed by studies such as by Hibino et al. (2005), Yamashita et al. (2006). However,

[*] Corresponding author.

the comfort evaluation system at the practical level has not been standardized. Also, it is difficult to evaluate the comfort of passengers during the stage of station space design. On the other hand, some railway companies carry out preliminary studies using pedestrian simulations, but these are voluntarily conducted by each company, which the result could be questionable and not suitable for practical usage. It is necessary to formulate a passenger comfort evaluation system for the reference during station design stage.

The purpose of this study is to develop a prototype of a passenger comfort assessment system in the space design of railway stations and to show an example of spatial assessment using the proposed assessment system. The assessment target in this study is passengers' stress to assess passengers' comfort. Besides, the development condition of the assessment system developed in this study is that it can be easily assessed using a general personal computer.

The analysis of this study consists of two parts: Part 1 (section 3 and section4) "Development of spatial assessment system of passengers' stress in railway stations" and Part 2 (section 5) "Analysis of passengers' stress". In the first part, we develop a system to assess passengers' stress in railway stations from the current pedestrian flow simulation results using an existing pedestrian simulator. In Part 2, the result from the simulation in Part 1 will be used to the assessment of the space in urban railway stations.

2. LITERATURE REVIEW AND SCOPE

Yamamoto et al. (2019) compare the design standards and technical ideas of Japanese and foreign urban railway passenger facilities. The study shows that while the UK and US incorporate passenger comfort at the design stage, Japanese standards only consider safety aspect. The study also suggested the need to construct a system that can pre-evaluate the passenger comfort before the investment of station infrastructure.

Furthermore, many papers suggested the need for station development that takes pedestrian behavior into consideration. (Hibino et al. (2005), Yamashita et al. (2006)). Suzuki et al. (2012) utilized the data of the flow survey at the subway station in Tokyo to investigate and analyze each bottleneck points, and proposed the allowable capacity as a quantitative index of safety. It is suggested that the bottleneck locations clarified using this index need to be further examined using detailed field surveys or pedestrian simulations. In recent years, some railway companies carry out pedestrian simulations as a preliminary study. However, the implementation of preliminary studies is highly voluntary. Most of the examinations are limited to the checking of pedestrian density in the station yard and the processing capacity of the elevating facility (stair, escalator, elevator, etc.). While studies such as Ishida et al. (2012), Suzuki et al. (2019), Tanemura et al. (2018), analyzed the comfort of pedestrians in specific railway stations as well as other pedestrian facilities. However, these studies used the data such as heart rate variability data, which is difficult to obtain in practice. According to Terabe (2016), customer satisfaction surveys by railway companies in Japan are rarely open to the public. The paper pointed out that customer satisfaction surveys at railway stations should be used more to improve service.

Although the need for station space analysis based on actual pedestrian behavior and passenger comfort has been pointed out, passenger comfort evaluation is still not implemented in practice. Based on the fact that Yamamoto et al. (2019) point out that passenger comfort is incorporated into the design stage of station space, this survey develops a prototype of a passenger comfort evaluation system at a railway station. Since the goal is to build a passenger comfort evaluation system that will mainly focus on the evaluation system for practical usage.

3. PREREQUISITES FOR THE DEVELOPMENT OF SPATIAL ASSESSMENT SYSTEM OF PASSENGERS' STRESS SYSTEM

3.1 Target passengers' stress of this study

There are many types of stress felt by passengers, including those caused by external factors (e.g., congestion) and those caused by internal factors (e.g., passengers' mental state). These multiple factors interact with each other to stress the passenger, who decides whether the space is comfortable or uncomfortable. Therefore, it is necessary to assess multiple types of stresses for spatial assessment. However, the psychological state of passengers will not be considered in this study as the survey requires a lot of costs and not consistent with the purpose of this study. Therefore, in this study, we assess the comfort of the station space by focusing on three points, which are important items for passenger comfort and are relatively easy to be assessed in practice.

3.1.1 Stress by high density

Matsushima et al. (2010) demonstrated that stress increases as the number of pedestrians increase. Also, although the pedestrian density is not standardized in the space design of Japanese railway companies, many companies incorporate it into the simulation at the station facility design stage, which indicate pedestrian density is widely used in practice. When assessing pedestrian space, the service level proposed by Fruin (1971) is commonly used worldwide.

3.1.2 Stress by slowdown

In general, passengers want to reach their goals as fast as possible. Assuming that each passenger has the desired walking speed, it is considered that the greater the decrease in speed caused by congestion or obstacles, the more stress is felt.

3.1.3 Stress by interweaving with others

The paper by Iryo et al. (2015) showed that when pedestrians cross each other, they are forced to take evasive action, which increases the movement burden of pedestrians. Therefore, the idea of this study is that the pedestrians are more stressed when interweaving with others compare to when there is no interweaving with others.

3.1.4 Summary of target passengers' stress of this study

Regarding the stress by slowdown and the stress by interweaving with others, there is no evidence of any assessment at the practical level where these stress were considered. However, the study by Iryo et al. (2015) showed that these stresses affect the comfort of passengers in the station space. Therefore, this study will also considered the stress by slowdown and the stress by interweaving with others, along with stress by high density as three indicators of passenger stress.

3.2 Overview of evaluation system (prototype)

The following tables show the outline of the prototype developed in this research. Table 1 shows the input/output data of the assessment system. Table 2 shows the outline of the assessment system. The assessment system consists of two subsystems. The subsystem 1 provides a simulation that reproduce the current pedestrian behavior using a pedestrian simulator. In the subsystem 2, the results of the simulation obtained in subsystem 1 are used to formulate and calculate the above-mentioned stress indicators. Finally, the result of the passenger stress indicator from the assessment system is visualized for each location in the station.

Table 1. Assessment input and output data

Input data	1) Structural data of station space Floor plans by floor (preferably showing detail station facilities such as waiting rooms and platform screen doors in addition to platforms, elevators, escalators) Cross-section (floor height data) 2) Data of time when train doors open It is used to set the opening and closing times of train doors which is used to determine the arrival and departure time of passengers to/from train. Time data in seconds is preferred. 3) Station pedestrian OD data OD pedestrian volume between each arriving train and station entrances/exits. OD data is prepared by attributes such as daily commuters/non-daily commuters. 4) Passenger behavioral characteristics Set the desired walking speed, gender ratio, etc. for each attribute.
Output data	1) Passenger flow inside the station Pedestrian simulation video displayed in three dimensions 2) Passenger stress indicator by location in the station Results of visually displaying three stress indicators

Table 2. Outline of the spatial assessment system of moving passengers' stress

Subsystem 1: Conducting current passenger flow simulation
1. "Viswalk" from PTV is used as the pedestrian simulator. Viswalk is based on the social force model, which assumes that pedestrians receive gravity toward their destination and repulsive force against obstacles and other pedestrians. (Figure 1) Viswalk allows the modeler to reflect more realistic walking behavior. 2. Based on the results of the field survey, the pedestrian parameters of passengers are adjusted to reflect the actual pedestrian behavior. Viswalk has seven pedestrian model parameters. These parameters were adjusted based on the result of the field survey to reflect the walking attribute of Japanese. (Table 3) 3. As a simulation result, data such as walking time, distance, and speed for each pedestrian can be obtained.
Subsystem 2: Implementation of comfort evaluation in station space [new development]
Input data: Passenger flow results obtained by subsystem 1 (time required for each pedestrian [s], distance traveled [m], actual walking speed vector [km/h, θ], etc.) The input data will be used to calculate the three stress evaluation indicators mentioned in section 3.1.

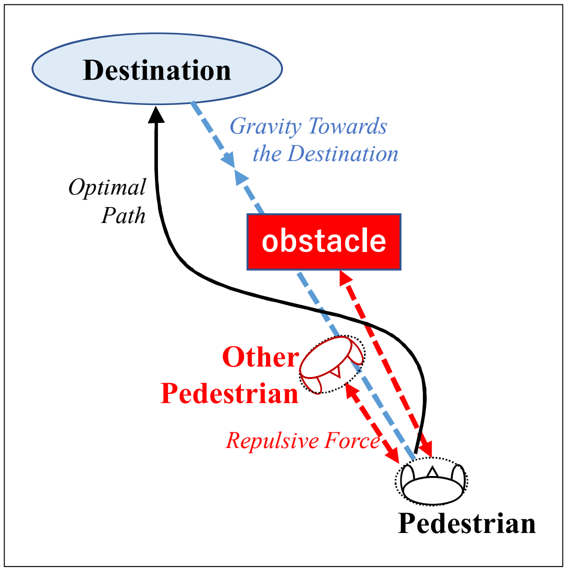


Figure 1. Image of social force model

Table 3. Pedestrian behavior parameters in Viswalk

No.	Parameter <>: Parameter name in Viswalk	Contents	The value set in this study
1	Relaxation time <Tau>	Relaxation time or inertia can be associated with response time. The default value is 0.4s	0.400 (Default value:0.400)
2	The degree of anisotropy of the force <Lambda>	Lambda controls the degree of anisotropy of the force.	0.176-0.425* (Default value:0.176)
3	Control of force between pedestrians <A_soclso>, <B_soclso>	A social (isotropic) and B social (isotropic) govern the force between pedestrians. B social (isotropic) and A social (isotropic) govern the force between pedestrians.	A:1.680-2.720* (Default value:2.720) B:0.200 (Default value:0.200)
4	Control of force between pedestrians (average value) <A_soc_mean>, <B_soc_mean>	A social (mean) governs the strength (A) of the social force between two pedestrians. B social (mean) governs the range (B) of the social force between two pedestrians.	A:0.400 (Default value:0.400) B:2.800 (Default value:2.800)
5	Number of influence pedestrian <React_to_n>	Reaction to pedestrians. During the calculation of the overall force on pedestrians, only the influence exerted by the n closest pedestrians is considered.	8.000 (Default value:8)
6	Disturbance of walking <Noise>	The greater this parameter value, the stronger the random force applied to the systematically calculated force if a	1.200 (Default value:1.200)

		pedestrian remains below his desired speed (i.e. path with obstacles) for a certain time.	
7	How to pass <Side_preference>	Specifies whether opposing pedestrian flows prefer using the right or the left side when passing each other.	None (Default value: None)

* Set vary depending on the congestion level of each place in the station.

4. DEVELOPMENT OF AND SPATIAL SYSTEM OF MOVING PASSENNGERS' STRESS IN RAILWAY STATIONS

4.1 Conducting a field survey

A field survey was conducted to collect basic data for executing pedestrian simulation in the subsystem 1. Table 4 shows the outline of the field survey. The target stations of the field survey are two urban railway stations with a large number of passengers throughout the day. The reason for this is to observe not only the morning and evening commuting peak hours, but also to observe the pedestrian behavior during the off-peak hours. No significant delays occurred during the survey time on the day.

Table 4. Outline of field survey

Target station	2 urban railway stations (Station A and Station B)
Survey date	Station A: Friday, November 6, 2020 Station B: Friday, October 23, 2020
Target time	8: 00-8: 30 (morning rush hour), 14: 00-14: 30 (off-peak), 18: 00-18: 30 (evening rush hour)
Target location	Platform and Stairs / Escalators
Acquired data	Understanding the number of people passing through stairs and escalators, the boarding queue length, and the congestion pattern near the stairs and escalators, walking speed
Survey method	Record the target area with a video camera, measure the number of passengers and analyze the behavior of pedestrians

4.2 Station modeling and settings

Subsystem 2 is explained by taking the implementation in the simulation as an example. The model settings are as follows. Evaluation is section-based. As shown in Figure 2, the assessment from the simulation was set as a part of the platform. The assessment area of one section was set as a square of 2m × 2m. Table 5 shows the assumption of passenger's desired walking speed settings in the simulation, which is set based on the result of the field survey mentioned in section 4.1. The simulation period is 30 minutes from 8:00 AM to 8:30 AM during the morning peak hour.

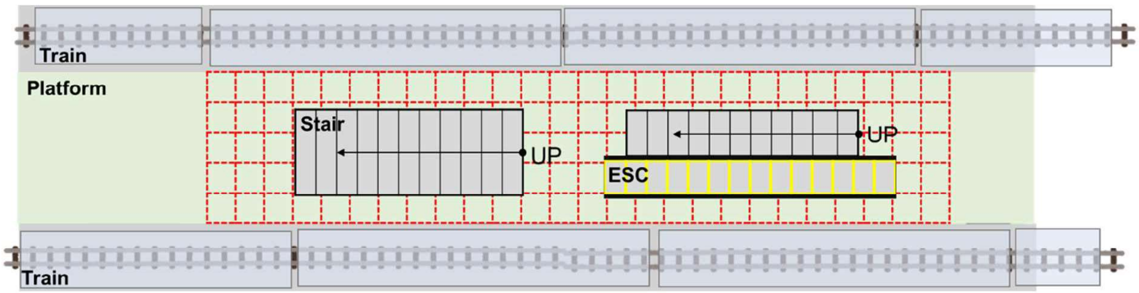


Figure 2. Section settings in the simulation (shown in dashed line)

Table 5. Setting the passenger's desired walking speed in the simulation

	Desired walking speed	Gender ratio
Male	4.0-5.8km/h	70%
Female	4.0-4.8km/h	30%

4.3 Pedestrian stress indicators

In this section, indicators to evaluate the pedestrian stress listed in 3.1 will be shown. The time interval Δt is set to 10 seconds in the simulation.

4.3.1 Pedestrian density (D) [ped/ m^2]

Pedestrian density (D) in the unit of ped / m2 is calculated at a certain section S and a certain time T (= t + Δt). In the simulation, the pedestrian density (waiting space) indicator proposed by Fruin (1971) is applied.

Table 6. The rank of pedestrian density (waiting space) indicator by Fruin (1971)

A	0～0.828 ped / m^2
B	0.828～1.076 ped / m^2
C	1.076～1.538 ped / m^2
D	1.538～3.588 ped / m^2
E	3.588～5.382 ped / m^2
F	5.382～ped / m^2

4.3.2 Speed reduction (R)

Using the desired walking speed V_d of the individual i in a certain section S and the actual walking speed V_a, the degree of speed reduction (eq. 1) at a certain section S and a certain time T (= t + Δt) can be calculated.

$$\text{Speed reduction indicator } R = \frac{1}{n}\sum_{i=1}^{n} r_i$$
$$r_i = 1 - \frac{V_{ia}}{V_{id}} \qquad (1)$$

where,

n: Number of people in Section S
V_a: Actual walking speed [km / h]
V_d: Desired walking speed [km / h]

The categorization shown in Figure 3 was categorized based on the frequency distribution of the average speed reduction R in the simulation. Similar to the pedestrian density, we propose the categorization of the speed reduction indicator in 6 ranks.

Figure 4 shows the example of the condition of speed reduction in each level from the simulation. A-rank is represented by the indicator of 0.1 or less, while the F-rank is 0.5 or more, which indicate that the actual walking speed is less than the half of the desired walking speed. In Figure 3, the indicators of 0 or less (the actual walking speed exceeds the desired walking speed) could be obtained. The reason for this is that the actual walking speed may exceed the desired walking speed because in the simulation, is it possible that the pedestrian is being pushed by another person.

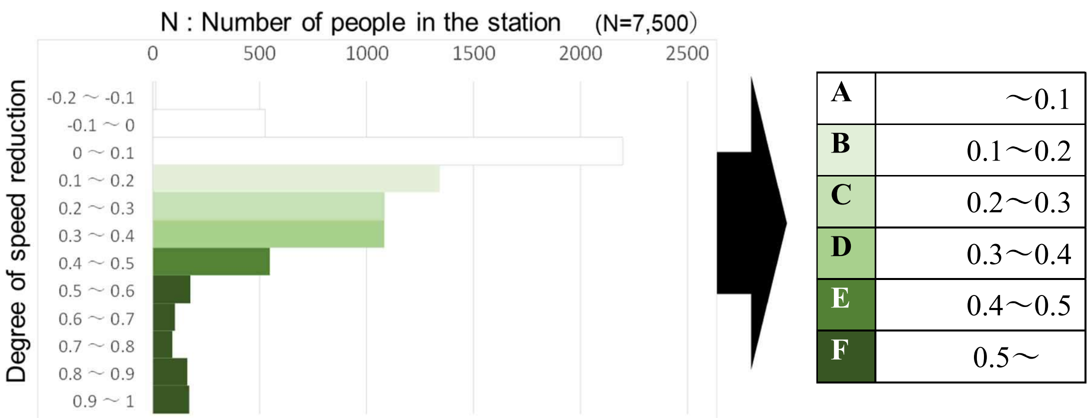


Figure 3. Distribution and categorization of speed reduction indicator (R)

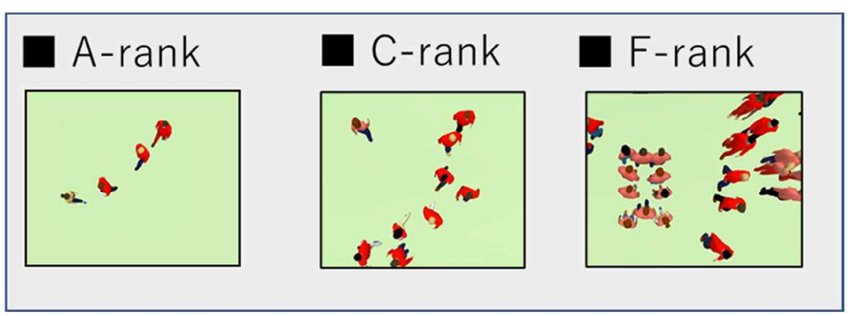


Figure 4. The example of situation from each speed reduction rank (from simulation)

4.3.3 Interweaving with others (M)

Interweaving indicator is represented by the average value of the degree of interweaving with others in section S using the walking direction vector. Based on the walking direction vector of pedestrian i, j, the interweaving angle θ_{ij} is calculated. As shown in Figure 5, this indicator is based on the idea that the greater the angle of intersection with others, the greater the stress it is. Equation (2) is the degree of interweaving with others in section, and equation (3) is the degree of interweaving with others per one time of interweave.

Total degree of interweaving with others, at section s, time t,

$$\mathrm{M}_{s,t} = \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\mathbf{1 - \cos\theta_{ij}}}{\mathbf{2}} \tag{2}$$

Average degree of interweaving with others per one time of interweaving, at section s, time t,

$$\mathrm{M'}_{s,t} = \frac{1}{n(n-1)} \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\mathbf{1 - \cos\theta_{ij}}}{\mathbf{2}} \tag{3}$$

where,

n: Number of people in a specific section s, at the specific evaluation period t
θ_{ij}: Crossing angle between pedestrian i and others j ($0° < \theta < 180°$)

The categorization was set based on the frequency distribution by the degree of interweaving in the simulation, the same method as in speed reduction indicator. Similarly, as shown in Figure 6 and Figure 7, we propose the categorization of the interweaving indicator in 6 ranks.

Figure 8 shows the example of the interweaving condition (M) in each rank from the simulation. When the number of samples in the section is n is 2, the crossing angle is less than 25° in the A-rank, and the crossing angle is 115° or more in the F-rank.

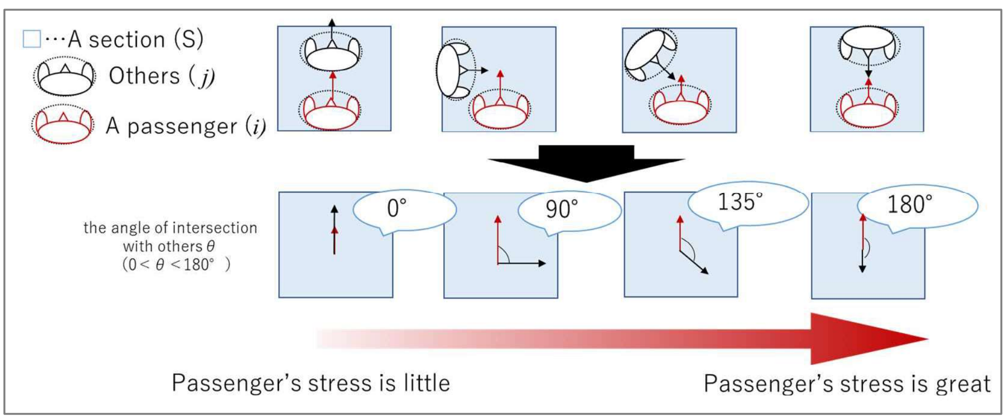
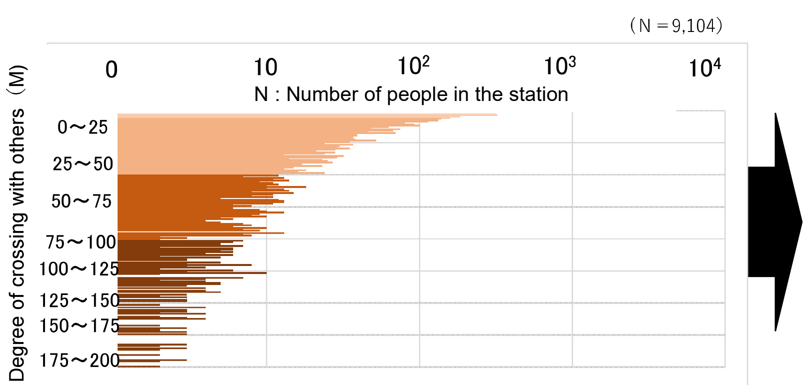
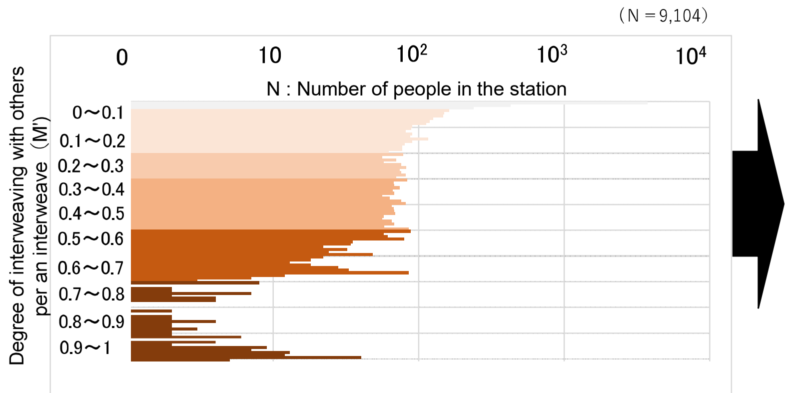


Figure 5. Examples of crossing at different angles



A	～0.05
B	0.05～1.50
C	1.50～5.00
D	5.00～50.0
E	50.0～100
F	100～

Figure 6. Distribution and categorization of interweaving indicator (M)



A	～0.05
B	0.05～0.2
C	0.2～0.3
D	0.3～0.5
E	0.5～0.7
F	0.7～

Figure 7. Distribution and categorization of interweaving indicator (per one time interweave) (M')

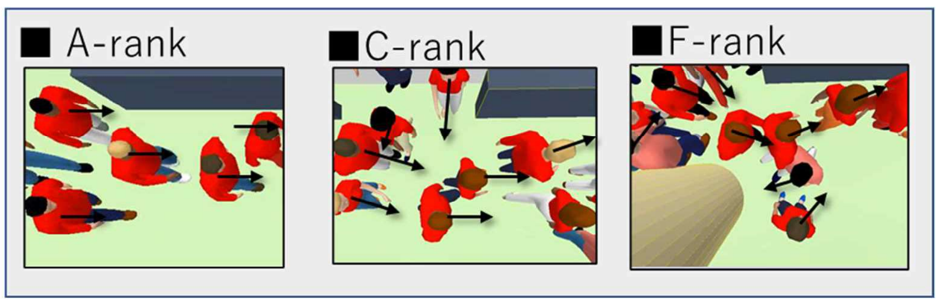


Figure 8. The example of interweaving(M) situation from rank (from simulation)

4.4 Verification of simulation reproducibility

Table 7 shows the results of the field survey conducted in subsystem 1 and the confirmation items to verify the reproducibility of the pedestrian simulation. In addition to the clearance time[1] and the number of people passing through stairs and escalators, which are generally used in practice, three stress indicators used in subsystem 2 are also used for the verification as shown in Table 7.

Table 7. Items in simulation reproducibility verification

No.	Item	Error
1	Clearance time	Within 5%
2	Number of people passing through stairs and escalator	Within 5%
3	Pedestrian density	Within 10%
4	Speed reduction	Visual confirmation
5	Interweaving	Visual confirmation

[1] Time between train departure time and time when the last passenger past through stair/escalator

5. ANALYSIS OF PASSENGERS' STRESS

Based on the result of the simulation, indicators were calculated at 10-seconds intervals. In this section, we analyze the results for 20 to 30 seconds after the arrival of the arrival at Track No.1. (Figure 9)

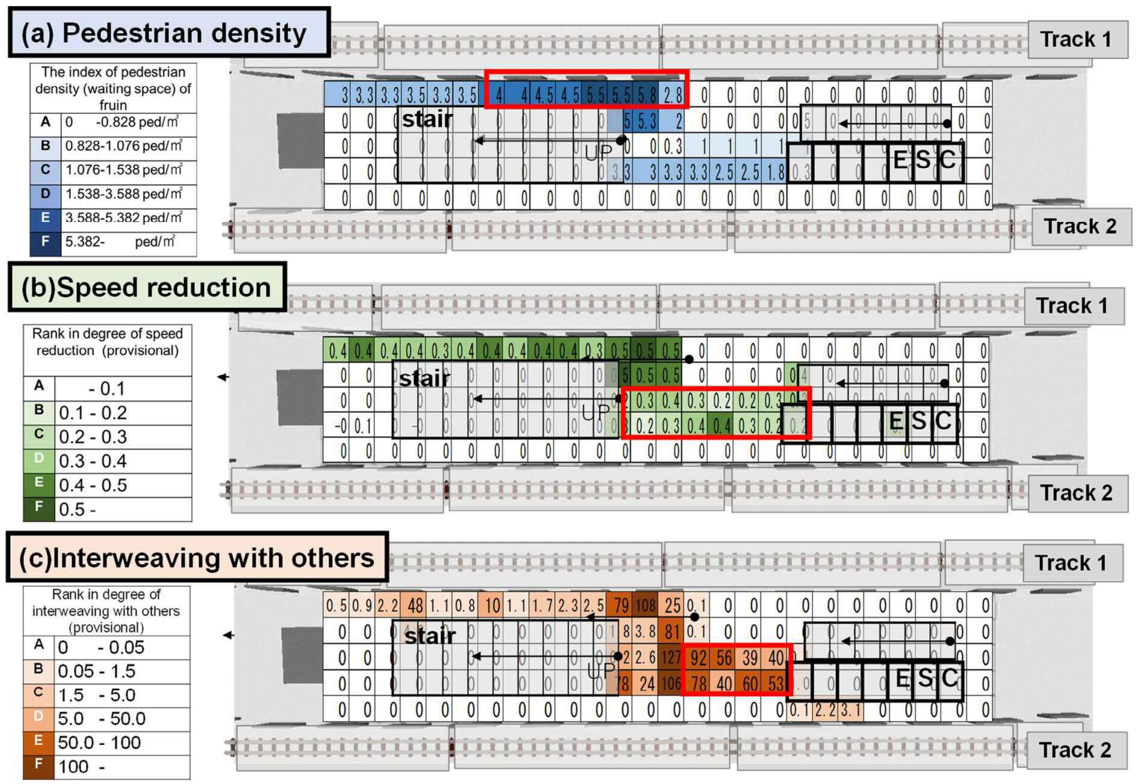


Figure 9. Assessment map
Stress indicators shown in each grid are calculated from simulation (20 to 30 seconds after the arrival of track No.1)

5.1 Results of pedestrian density (D)

The result shows that the track 1 platform where the train arrived, especially the section on the side of the stairs (highlighted in red in Figure 9 (a)) has a high pedestrian density indicator of E-rank and F-rank. The simulation also confirms that during 20 to 30 seconds after the arrival of the train, the lines of passengers getting off from the train are starting to form along the side of the stairs.

5.2 Result of speed reduction (R)

Similar to the pedestrian density, D-rank, E-rank, and F-rank speed reduction can be found on the side of the stairs (track 1 platform). Also, it is found that D-rank and E-rank occur in the lower part of the stairs (highlighted in red in Figure 9 (b)) where the poor assessment could not be found in pedestrian density. On the side of the stairs, speed reduction could be the result from high pedestrian density. However, in the lower part of stairs, speed reduction could be the result from the interweaving of passengers near the stairs. Figure 10 shows the staircase operation settings in the simulation. This operation is effective to manage the flow of passengers getting off when trains from both platforms arrive at the same time. However, during times when there are many boarding passengers from the concourse level (in this simulation, passengers going down the stairs), high frequency of interweaving movement between passengers getting off and passengers getting on board can be expected.

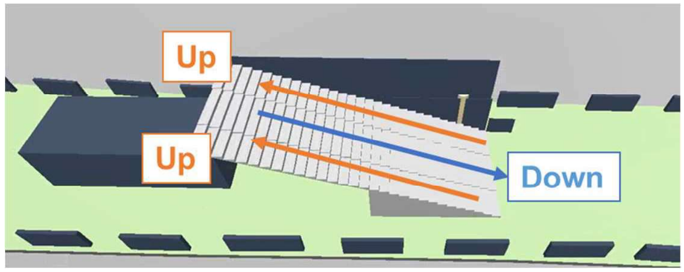


Figure 10. Stair operation setting in the simulation

5.3 Results of interweaving with others (M)

On the side of the stairs on track No.1nterweaving indicator is ranked A-rank, indicating that the passengers' stress in these sections are small. However, these sections show a relatively poor assessment in terms of pedestrian density and speed reduction. This is because all passengers getting off the train are heading for the concourse level and moving in the same direction, so the crossing angle is close to 0. However, D-rank and E-rank were found in the lower part of the stairs (highlighted in red in Figure 9 (c)), same as found in the speed reduction. The result also suggests that there may be some correlation between the result of speed reduction indicator and the interweaving indicator.

5.4 Discussion

In the simulation, it was confirmed that problems occurred in different parts of the platform. Analyze the relationship between the output three indicators. Figure 11 shows the deviation values of the three indicators on a radar chart and extracts sections where all three indicators are high, sections where Speed reduction is extremely high, and sections where Interweaving is extremely high. Analyze the relationship between the output three indicators. Figure 11 shows the deviation values of the three indicators on a radar chart, and extracts sections where all three indicators are high, sections with significantly higher " Speed reduction", and sections with significantly higher "Interweaving with others". In addition, mapping was done for the locations of those characteristic sections. From the map, it was found that the sections where all three indicators were high, the sections where Speed reduction was extremely high, and the sections where Interweaving was extremely high were different. By checking the pedestrian density, problems can be found in the purple sections of the map, but problems cannot be found in the green and orange sections. This suggests the effectiveness of evaluating not only pedestrian density but also Speed reduction and Interweaving.

In this paper, the calculation result of one case is shown. In the future, it is expected that points to be noted will become clear, such as the points where problems occur will become constant by repeating the simulation. The evaluation ranks set in the three items are tentatively set in the simulation, and it is necessary to proceed with the study in the future.

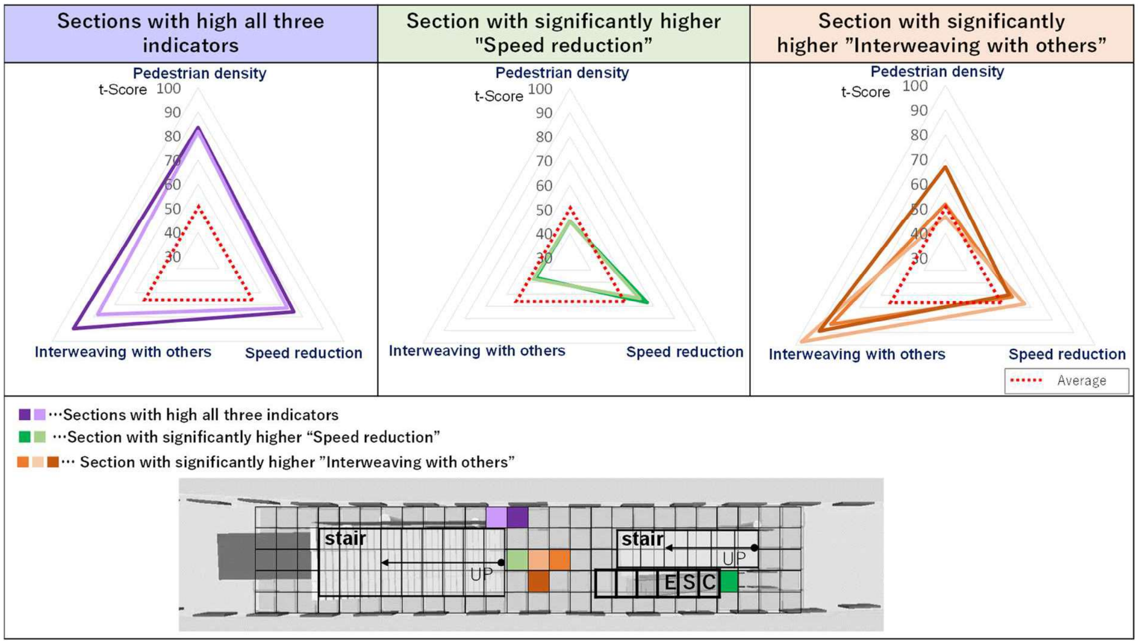


Figure 11. Sections with significantly higher values for each indicator

6. CONCLUSIONS

This study proposes the assessment system of moving passengers' stress in railway stations, focusing on the stress associated with pedestrian density, the stress associated with reduction in walking speed, and the stress associated with interweaving with other passengers. The proposed evaluation system provides a simple and effective assessment method by utilizing the commercial simulation software "Viswalk". Besides, by using the proposed system using the newly developed indicators, it is possible to identify problems that cannot be confirmed only by the pedestrian density.

In this study, an example of a part of the platforms was shown. However, the method can be also applied to other station space such as concourses, retail spaces, as well as the walkway. Furthermore, regarding the reproduction of the simulation results in this study and the measurement results in the field, only the number of passing people and the handling time were confirmed by comparing with the observed images. In other words, although a certain level of reproducibility has been confirmed for pedestrian density, reproducibility has not been confirmed for speed reduction and interweaving. In the future, it will be necessary to confirm the reproducibility of speed reduction and Interweaving, and if it is judged that their reproducibility is insufficient, efforts will be made to improve the reproducibility.

In addition, stress is closely related to human psychology. Actual stress data from methods such as interview survey, heart rate detection, and saliva test to check the validity of the indicators regarding the effects of the three proposed indicators on human psychology. Furthermore, it is also important to improve the usability of the assessment system by reducing the calculating and modeling time by automating the assessment system. By passing these tasks and performing case studies in various walking spaces, the quality of the proposed evaluation system will be improved. More results from different case studies will help to determine the right number and placement of elevating facilities, ticket gates, commercial facilities, etc.

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REFERENCES

Yamamoto, K., Ieda, H. (2019) International comparison of capacity design standards for passenger facilities in urban railways and their operation-Basic planning concept and future. *The Proceedings of Infrastructure Planning*, 60, 14pages, [in Japanese].

Hibino, N., Yamashita, Y., Uchiyama, H. (2005) A Study on Usage of Pedestrian Behavioral Data from Video Camera in Railway Stations. *Infrastructure planning review*, 22(3), 531–539, [in Japanese].

Yamashita, Y., Sekiguchi, T., Uchiyama, H. (2006) A Study on the Crossing Phenomenon at the Walking Space in the Railway Station. *Infrastructure planning review*, 23(2), 489–495, [in Japanese].

Hase, A., Hibino, N., Morichi, S. (2014) Influence of Plan to Passengers' Flow in A Metro Station. *Proceedings of infrastructure planning*, 53, 13pages, [in Japanese].

Ishida, S., Takeda, W., Shirakawa, T., Kashima, S (2012) Assessment of Stress Relief Effect in Railway Services. *Transport policy studies' review*, 15(2), 010-019, [in Japanese].

Suzuki, Y., Nishio, N., Ito, F. (2019) Proposal of estimation method of walking stress level using heart rate variability and application in urban area analysis. *Journal of the City Planning Institute of Japan*, 54(3), 811-817, [in Japanese].

Fruin, J.J (1971) Pedestrian Planning and Design. *J Metropolitan Association of Urban Designers and Environmental Planners*, New York.

Iryo, M., Nagashima, A (2015) Performance Evaluation of Pedestrian Crossing Flow. *Monthly journal of the Institute of Industrial Science, University of Tokyo*, 67(2), 369-373, [in Japanese].

Nakamura, Y., Hibino, N., Morichi, S (2011) A Study on Congestion and Passenger Flow in Railway Station. *Infrastructure planning review*, 67(5), I705–I713, [in Japanese].

Takayanagi, H., Sano, T, Watanabe, H (2001) A Study on The Pedestrian Occupied Territory in The Crossing Flow: The analysis with pedestrian territory model. *Transactions of AIJ. Journal of architecture, planning and environmental engineering*, 66(549), 185–191, [in Japanese].

D. Helbing and P. Molnár (1995). Social force model for pedestrian dynamics. Physical Review E 51(5), p. 4282-4286.

Yamashita, Y. (2017) Current Status of Studies on Passenger Flow in Crowded Urban Railway Station for Safety Enhancement. *IATSS Review*, 41(3), 38–43, [in Japanese].

Okunobo, N, Ikeda, N., Zhuang, Z., Hanaue, M.,Yamashita, Y., Tsuruike, K. (2013) Hokousya mikuro simyure-syon wo mochiita ekikounai ryokaku ryudou bunseki ni kansuru kenkyu (Research on passenger flow analysis in station premises using pedestrian micro-simulation). *The Proceedings of Infrastructure Planning*, 47, 3pages, [in Japanese].

Tanemura, K., Matsubara, G., Kanasugi, H., Hino, T., Shibasaki, R (2018) A Study on Quality of Transportation Index by Using Personal Data. *Research Abstracts on Spatial Information Science CSIS DAYS 2018*, 4pages, [in Japanese].

Suzuki, A., Hibino, N., Morichi, S. (2012) A Study on Facility Capacity and Congestion of the Railway Stations by Redevelopment at CBD. *Transport Policy Studies' Reciew,* 15(3),2-9, [in Japanese].

Terabe, S (2016) Kokyo-koutsu sa-bisu hyoka ni kokyaku manzokudo wo katsuyo siyou (Use customer satisfaction to evaluate public transport services). *Transport Policy Studies' Review,* 18(4),49-50, [in Japanese].