A Study on the Evaluation Method for Local Congestion in Pedestrian Spaces Using the Traj-Scalar Model

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Abstract
The regeneration and maintenance of large-scale station environments is planned for high functionality with integrated urban functions. Such highly functional space is required to safely and comfortably accommodate extremely dense crowds. It is more strongly required than before to objectively evaluate the design of a space in terms of crowd control. The purpose of this study is to visualize the place and the degree of local congestion in order to allow an intuitive grasp based on the analysis of crowd behavior.

Keywords: pedestrian flow; congestion; crowd behavior; visualization

1. Introduction
1.1 Research Backgrounds
In crowded spaces such as a large-scale terminal station or urban complex, various accidents and troubles occur between pedestrians day and night. This seems to be caused by the complexity of railway networks, diversity of urban transportation, and concentration of populations in urban areas. In the future, urban environments and pedestrian spaces need to have high functionality. To perceive walking crowd accidents such as those described above, a local congestion evaluation model to support the design of safe and comfortable walking environments is necessary. The authors of this paper have carried out an intensive study to evaluate crowd flow as a molecular dynamics flow and simulation system to perform a spatial evaluation from crowd density distribution. Also in this paper, a non-stable passing interaction between pedestrians has been visualized accurately by using the "Traj-Scalar method", and local congestion of pedestrian space was evaluated.

1.2 Purpose of Study
The purpose of this study, based on research and an analysis of crowd behavior, is to define the "Traj-Scalar method" that can visualize and indicate the local (or partial) congestion status of pedestrian spaces.

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projected to the place of occurrence. This is a suitable method to visualize the congestion properties on 3D-CAAD platforms.

1) Duration of interference of territory occurs
2) Increase or decrease in walking speed
3) Disturbance of the walking trajectory
4) Minimum distance in interference of pedestrian territory

Takayanagi and Sano studied the results of this definition. Over 1.20 persons/sq. m or more of the crowd density space that is suppressing the action and local congestion of crowded spaces can be explained from the four above. Pedestrians walking in the same direction have an influence on each other in a free pedestrian space. However, overcrowding occurs and this influence needs to be taken into account. In contrast, pedestrians who move in the opposite direction always exert an influence on each other in the same space as passing occurs, and therefore this case has more to be considered than movement in the same direction. This study makes an attempt to establish a method focusing on the influence of pedestrian territory interference by the mutual intersection of pedestrians moving in multi-directions. The Traj-Scalar method uses two kinds of interference factor visualization models known as the C-T Marker (Contacting-Time Marker) and C-D Marker (Contacting-Distance Marker) to visualize the behavior of pedestrian territory interference on a computer.

2.2 Specification of C-T Marker

The C-T Marker is defined as a model that visualizes three interference factors -a) a period of time during the occurrence of interference, b) a change in walking speed, and c) a change in pedestrian trajectory – with a starting time of pedestrian territory interference between a mobile entity $i$ (pedestrian territory radius 0.455 m) and another entity on the plane (Fig.1.). The C-T Marker that has an occurrence position at the centroid of a mobile entity is configured with a bar-type rectangular model which occurs every 3 frames and has a long side of 0.91 m, the same length as pedestrian territory, and with a line-type model which occurs continuously and visualizes the trajectory (Table 1.). When pedestrians $i$ and $j$ approach each other, pedestrian $i$ walks while taking their next action into consideration, such as whether to dodge or to follow pedestrian $j$. When the pedestrians are at a sufficient distance from each other, such consideration is not necessary, and thus the pedestrians appear to be loaded when they approach. Therefore, in this study, the C-T Marker is only generated during close approach behavior during pedestrian territory interference.

![Fig.1. Visualization of Interference Factors by C-T Marker](image)

Table 1. Occurrence Process of C-T Marker, C-D Marker

| Step | Relations of the Facing Points | C-T marker | C-D marker |
|------|--------------------------------|------------|------------|
| 1    | No pedestrians interfering    | No interfering occurred | No interfering occurred |
| 2    | Interferring status           | C-T marker occurs in position of Pedestrian $i$ and Pedestrian $j$'s field | C-D marker |
| 3    | Minimum distance moving away  | C-T marker finished | C-D marker |
| 4    | Interferring interrupted      | C-T marker bumped every 0.1 sec. | C-D marker |
| 5    | Interferring finished         | Interferring finished | Such marker removed |

Table 2. C-T Marker Status and the Criteria

| Status | Description | Criteria |
|--------|-------------|----------|
| Normal | Walking the area indicated by the survey results of Takayanagi et al. (limitations reflect the possible crossing of obstacles) | 0.001 m |
| Medium | Walking the area indicated by the survey results of Takayanagi et al. (limitations reflect the possible crossing of obstacles) | 0.01 m |
| High   | Walking the area indicated by the survey results of Takayanagi et al. (limitations reflect the possible crossing of obstacles) | 0.05 m |

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2.3 Specification of C-D Marker

The C-D Marker is defined as a circular model that occurs in the centroid position \( p(x, y) \) of only one entity \( i \), when pedestrian territory interference occurs between mobile entities \( i \) and \( j \) on the plane \( (x, y) \) and the distance between them becomes the minimum value (Table 1.). The C-D Marker has three kinds of RGB information, and the color is determined by the value of minimum distance \( D_{\text{min}} \) between \( i \) and \( j \) entities when the interference occurs (Table 2.). By using this function with the color information, the C-D Marker visualizes the minimum distance between pedestrians during interference. The overlap of rivalry area mutuality in Table 2. represents the pedestrian state in which the shoulders of two individuals hit, one individual avoids the hit by twisting their body, or the like in a real pedestrian space.

It is understood that the above state means a highly loaded state on pedestrians because they are so close to each other. In the C-D Marker, this state is the most highly-loaded state in interference and is illustrated with black (RGB[0,0,0]).

3. Extraction of Pedestrian Data
3.1 Field Survey by Video CAM

As a trial of the Traj-Scalar method, the authors will obtain the positional coordinates of pedestrians in sequential order in a real pedestrian space. In this study, the survey was conducted in nine station spaces and pedestrian crossings, and trajectory data from 1,070 people were obtained. A stable fixed video camcorder recorded crowd flow, and the trajectory data were obtained during the time between the entrance to and exit from the observation range of arbitrary pedestrians. However, for crossings in front of the S department store, the observation time was 10 seconds until an opposing crowd intersection subsided. And all of the research fields and details of the extracted data are listed in Table 4.

3.2 Extraction of Pedestrian Coordinates

The authors will obtain pedestrian positional coordinates from the recorded video images. In this study, the pedestrian centroid position \( \{x, y\} \) is defined as pedestrian positional coordinates in orthogonal coordinates horizontal to the earth plane. The reference plane is set to a height of 168 cm, and the pedestrian positions are plotted^2. By converting the positions into orthogonal coordinates, the authors obtained the positional coordinates (Table 3.).

4. Application to Actual Pedestrian Behavior
4.1 Operation on 3D CAAD Platform

An elemental model to comprise pedestrian space is produced by 3D CAAD with respect to the targeted pedestrian crossing in front of “S department store” in Tokyo. To distinguish a crowd from the total crowd, crowd A toward the north is colored green and crowd B toward the south is colored gray. Reproduced animation of a pedestrian space is generated by inputting the trajectory data of pedestrians to the element model (Fig.2.).

4.2 Space Evaluation by Application

The authors will produce six cases of reproduced animation and comparatively evaluate the congestion states by the Traj-Scalar method. First, according to the data output from the Traj-Scalar method, they are largely classified into comb-shaped intersections (Table 5., Cases 1, 2, 3, 6) and wedge-shaped intersections
The wedge-shaped intersection represents a small group phenomenon that reduces a pedestrian disturbance by cutting into an opposite crowd by following up and tracking pedestrians in the same direction. From the Traj-Scalar method output data, the relationship between the shapes and congestion properties that appear on the C-T Marker can be categorized into five patterns

5. Application to Crowd Flow Simulation

Research is currently being carried out on touchless ticket gates that will not require the touch of an IC card. In the near future, it will be possible to pass through ticket gates without touching any machine through the use of IC cards or digital devices. With this technology, it is expected that congestion around gates will be reduced; however, at the same time, it is expected that the movement of pedestrians in station concourses will differ from current movements due to a decrease in ticket-vending machines. This may lead to unexpected local congestion. In this study, the...
change in traffic lines in association with this touchless gating will be verified using the Traj-Scalar method.

5.1 Station "Touch-less Gate"

Targeting the east exit ticket gate of Sj station, the authors will model a space using surveyed data to examine the behavior of crowd flow by OD survey. The crowd surveyed in the targeted space is classified into four types, and a simulation using a multi-agent model is performed (Fig.4.). Mathematical criteria that are applied to the agents are shown in Table 7.

5.2 Results of Simulation

A simulation trial was conducted for one minute by implementing the Traj-Scalar method in a simulation space. Local congestion that occurred in the meantime was evaluated by a C-T Marker. It should be noted that pedestrian territory interference between pedestrians of the same group was not taken into consideration. In this study, four patterns of traffic flow were verified.

In the C-T Marker that occurred after the simulation, a group of C-T Markers that have a distinctive shape from others were seen (Fig.6.). The mutual behavior of moving individuals in the virtual space at this time has a process: 1) both stop because of the occurrence of a collision (speed: 0 m/s); 2) both turn around on the spot; and 3) both change their directions to avoid collision and then start to move.

Here, the authors will make a reference to the classification of the C-T Marker by the intersection patterns described in Chapter 4. Although there are some differences among all the shapes those occurrence processes are close to the collision type. It is apparent from previous articles that the collision type occurs when the load on pedestrians is high due to interference. In this study, therefore, we define the shape of a C-T Marker that is easily distinguishable from others as an "S collision type" shape that is a collision-type shape of a C-T Marker that occurs when the interference load is high in a simulation scene. This "S collision avoidance" can be an important index of local congestion. Table 8. is a summary of the analyses.

6. Conclusion

In this study, the authors have structured a Traj-Scalar method in order to visualize local pedestrian congestion. Evaluations of congestion states in a comb-type intersection, which cannot be differentiated by conventional indicators, were performed by examining the crowd behavior in a conventional space. An index of the evaluation was created by categorizing the behavior modes of the Traj-Scalar method. Furthermore, the result of this study is that local congestion in the total space is demonstrated by the simulation, focusing on individual intersections.

Table 8. Visual Evaluation of Local (or partial) Congestion

|Congestion state | Total View | Local View |
|------------------|------------|------------|
|Implementation of the previous ticketing gate | A new line of flow at the gate, and the congestion of the ticket gate neighborhood was reduced in a method to change the passage direction of the gate as shown in Fig.5. | A new line of flow at the gate, and the congestion of the ticket gate neighborhood was reduced in a method to change the passage direction of the gate as shown in Fig.5. |
|Congestion avoidance at C-T Marker | A new line of flow at the gate, and the congestion of the ticket gate neighborhood was reduced in a method to change the passage direction of the gate as shown in Fig.5. | A new line of flow at the gate, and the congestion of the ticket gate neighborhood was reduced in a method to change the passage direction of the gate as shown in Fig.5. |

Fig.5. Flow Simulation on 3D CAAD

Fig.6. Typical Type of "S Collision Avoidance"
Notes

1 Pedestrian territory interference: a pedestrian interferes with the territory (which is a minimum region to be secured so that a pedestrian dodges or overtakes another, radius: 0.455 m) of another pedestrian.

2 The average height of 2014 Japanese men (20-54 years old) is 171.0cm. And the same data of women (20-54 years old) is 158.0cm. These average values are 164.5cm. To this was added the height of about 3.5cm of a shoe sole, so the average pedestrian height in the video survey (the top of the head height) was 168.0cm.

3 In previous studies by the authors, a non-stable small group in crowd flow forms at least four distinctive formations. This is based on the reference 6). Its four distinctive patterns are categorized by duration of interference time (sec.) and amount of average interference area (sq. m). Now in this study, in addition to these four, more than one characteristic form has been watched, leading to indicate the five model patterns as shown in Table 6.

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