Assessment model for the Stability Situation of Crowd Evacuation based on Thermodynamic Map

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Abstract. To solve the shortcomings of the conventional assessment methods for crowd evacuation stability, such as over-reliance on the experience of the judges, obvious subjectivity and time-space limitations, this paper proposes an assessment model for judgment on the stability situation of crowd evacuation. Furthermore, the scenarios of large-scale crowd evacuation is diverse, and the compositions of crowd, the causes of crowd trampling are different. So it is particularly important to analyze specific problems for different scenarios. However, different data acquisition and poor real-time performance are main practical problems of judgment on the stability situation of large-scale crowd evacuation. With regard to shortcomings and problems above, the assessment model proposed in this paper uses big data technology to figure out a real-time crowd distribution thermodynamic map and obtain the crowd distribution density data. According to the criterion of crowd stability proposed by the Green Guide in Britain, the assessment model is further constructed to judge the stability situation of large-scale crowd evacuation in real-time.

1. Instruction

With the sustainable development of social economy and culture, various public place are undertaking more and more large-scale crowd gathering activities. Once an emergency occurs in a crowded scenario, the crowd will spontaneously rush to the escape exit, which makes the population density increase sharply, extremely probable to cause overcrowding and trampling events, leading to serious casualties[1,2]. In recent years, crowded stampedes have occurred frequently all over the world. Table 1 shows the worldwide large-scale stampedes that have caused serious casualties in recent years.

| Incident time  | Country/Region         | Place of occurrence        | Number of casualties |
|---------------|------------------------|---------------------------|----------------------|
| July 2010     | Duisburg, Germany      | Music Carnival            | 500                  |
| November 2010 | Cambodia, Phnom Penh   | Water delivery Festival    | 1000                 |
| February 2011 | Bamako, Mali           | Stadium                   | 100                  |
| February 2013 | Allahabad, India       | Railway Station           | 96                   |
| December 2014 | Shanghai, China        | Chen Yi Square on the Bund| 80                   |
| September 2015| Mecca, Mina            | Stone-throwing and T-junction| 3300              |
| May 2017      | Tegucigalpa, Honduras  | Soccer Field              | 21                   |

The large-scale crowd evacuation is a complex system. It is urgent to use scientific methods to analyze the root causes of evacuation instability, because the large-scale crowd stampeded events have the characteristics of complex causes, strong randomness and usually occur in a variety of complex...
scenarios. In order to form scientific decision-making to prevent overcrowding and trampling, we need to study the evolution mechanism of evacuation stability and discover the knowledge of evacuation stability evolution contained in the typical crowded and stampeded scenarios.

So as to put forward effective knowledge to support scientific crisis decision-making, the research methods of crowd evacuation stability mainly focus on crowd modeling simulation and intelligent algorithm application at present. The researches of these methods must be driven by a large number of real-time and effective data. However, crowd evacuation under emergency situation is a complex process, which is affected by evacuees’ state of psychology, physiology and the features of occurrence scenarios, even the society. Therefore, different evacuation scenarios present their specific characteristics. Moreover, it is difficult to restore the accident itself accurately. So the data driving and acquisition of large-scale crowd evacuation have always been the obstacles to the in-depth study of the evolution characteristics of crowd evacuation stability.

With the development of security information, the use of big data in public security has gradually been concerned about. Big data technology is good at dealing with massive data, and has high speed of data processing. It can effectively mine and analyze data in deep. Big data has excellent advantages in crisis area for risk prediction and management[4]. To this end, this paper proposes a state assessment model for judgment on the stability of crowd evacuation based on big data technology, using the information uploaded by mobile phones and stored by base stations as large data sources. Through data screening and processing, effective data sets are formed, then the data sets are visualized by population distribution thermodynamic map. Based on the population distribution thermodynamic map, the real-time population distribution density data is derived as data source of the assessment model. Furthermore, the assessment model was based on the judgment criteria for stability of crowd evacuation, so as to provide scientific basis and guidance for crisis management of large-scale crowd evacuation.

2. Thermodynamic map principle

Previous research data sources of crowd evacuation mainly relied on crowd evacuation model simulation, evacuation drills and questionnaire survey, among which evacuation model simulation and drills cannot really restore the original condition of the design scenarios and evacuees’ psychological behaviors. Questionnaire survey method is affected by the number of investigators and the reliability of recall, which makes the data collected by the investigators not completely reliable.

In addition, the above methods are lagging behind the study, which can only provide basis for the prevention of crowd trampling in some way, but cannot provide real-time guidance for large-scale crowd evacuation events. Using crowd distribution thermodynamic map, more time-sensitive and accurate evacuation data can be obtained, to provide technical support to deal with large-scale activities.

According to reference [5], the formation principle of thermodynamic map of crowd distribution can be summarized as four steps:

Step 1: The measurement area is discretized, the center of the discrete mesh is taken as the center of the circle, and a circle is formed with a specific radius as a buffer.

$$A_i = f(x_i, y_i, \eta_i)$$

Where, represents a buffer region with $x_i, y_i$ as the center and $\eta_i$ as the radius.

Step 2: For each step, progressive gray bands (The complete gray scale is 0-255) are used to fill the buffer from inside to outside. In each buffer, the center is a circular point, and the heat attenuation is Gauss distribution.

$$G(x) = \frac{1}{\sqrt{2\pi}\eta}e^{-\frac{x^2}{2\eta^2}}$$

Step 3: In the intersection area of buffer, the gray values are overlapped. The more buffer intersection, the bigger gray value, the area in the thermodynamic map will be redder.

Assuming that there are two point $(x_i, y_i)$ and $(x_j, y_j)$, which have the intersection area. If $(x_i, y_i)$ is hotter than $(x_j, y_j)$, the gray values of the intersection is derived as follow:

$$G_j = \left(\frac{n_j}{h_i} \times 255\right) \cdot G_i$$
\[ G_A = G_i + G_j \] (4)

Where, \( G_i \) denotes the gray value of point \((x_i, y_i)\), \( G_j \) denotes the gray value of point \((x_j, y_j)\), \( G_A \) denotes the gray value of overlapping buffer.

Step 4: By indexing the overlapped gray value, the color is mapped from a 256 color band (e.g. rainbow color) and the image is re-colored to draw the thermodynamic map

3. Criteria of crowd evacuation stability

Stability refers to whether the system can recover to the original equilibrium state, when the system was disturbed by external forces and after the disturbance disappears[6]. If the disturbance in the system disappears and the system can gradually return to the original equilibrium state, the system is stable; If the disturbance disappears, the system cannot return to the original equilibrium state, then the system is unstable.

The study of stability is very important to prevent crowding and trampling in crowd evacuation. The stability of large-scale crowd evacuation system mainly depends on crowd density. According to the "Guide to Safety at Sports Grounds" [7], which is a safety standard for crowded people formulated by The Green Guide in Britain, this paper gives the criteria for determining the evacuation stability of crowds.

When the population density is between \(4p/m^2\) and \(7p/m^2\), the crowd is in a critical state, and when the population density is greater than \(7p/m^2\), the stampede is very easy to happen. The concrete judgment basis is as follows:

\[
\begin{align*}
\text{If } & \rho < 4 \text{ p/m}^2, & \text{Then, the system is stable} \\
\text{If } & 4 \text{p/m}^2 \leq \rho < 7 \text{ p/m}^2, & \text{Then, the system is critical stable} \\
\text{If } & \rho \geq 7 \text{ p/m}^2, & \text{Then, the system is unstable}
\end{align*}
\] (5)

When the population density is within the range of \(4p/m^2 \leq \rho < 7 \text{ p/m}^2\), the population is in dangerous state if the population velocity \(v > 1.5 \text{m/s}\).

4. Assessment model for Judgment on the Stability of Crowd Evacuation

Nowadays, everything can be connected through the Internet. The Internet era has changed to the era of big data. Under such background, the data extraction and mining has become a research hotspot. Meanwhile, large-scale evacuation data have the characteristic of typical mass, diversity and variability. Based on the characteristics of crowding and trampling accidents, Fanjing Zeng and Hefei Zhang put forward that big data technology has advantages in collecting and analyzing dangerous information, rapid forecasting of disasters and providing solutions for large-scale crowding and trampling accidents[8].

In crowds gathering places, real-time density and location information of crowds can be obtained by means of data acquisition tools or software self-collected data and special data acquisition agencies. In this paper, Batch and stream processing are used to aggregate and associate the massive data source. The processed data are stored as a useful data set for early warning analysis. Then, the data set stored is analyzed by intelligent algorithm, machine learning and data mining. Sequentially the statistical data are visually displayed through the thermodynamic map. Finally, based on the extracted real-time data and the criterion of evacuation stability proposed above, a situation assessment model of large-scale evacuation stability is established. The specific process of establishing the model is as follows:
5. Case Study

Shanghai Hongqiao Transportation Hub links up the high-speed rail transit, intercity traffic, and airport and so on. As an international first-class modern comprehensive transportation hub, it is crowded all the year round, and the crowd evacuation has always been the important problem for Shanghai crisis management department. This paper takes Shanghai Hongqiao Transportation Hub as the background to study the crowd stability based on thermodynamic map. Figure 1 shows the distribution of crowd in the waiting hall of Shanghai Railway Station on January 23, 2019.

![Figure 1. Assessment model for Stability Situation of Crowd Evacuation](image)

Using the Baidu Map application as a tool, the study calls the original data of the crowd distribution within 24 hours on January 23, 2019. At 15:30 p.m. on that day, the crowd distribution of Baidu thermodynamic map is shown in figure 3. It can be seen that the waiting hall of Shanghai Hongqiao Railway Station was very crowded.

![Figure 2. Distribution of crowd in the waiting hall of Shanghai Railway Station](image)
Using CAD software to process the original data obtained by Baidu thermodynamic map, the study calculates the measure of different color regions. Then, the corresponding population number \( N \) (per) in different color ranges is calculated, so that we can calculate the crowd density \( \rho \) in different scenarios. Table 2 shows the crowd density distribution of Shanghai Railway Station on January 23, 2019.

### Table 2. Crowd density distribution of Shanghai Railway Station

| Region                      | Measure of area \( S(m^2) \) | Crowd amount \( N \) (per) | Minimum | Maximum | \( \rho \) (per \( m^2 \)) |
|-----------------------------|-------------------------------|-----------------------------|---------|---------|---------------------------|
| Waiting Hall of Shanghai Railway Station | 11340                         | >23814                      | >47628  | >3.15   |
| Area of all Shanghai Railway Station | 240000                        | >96000                      | >312000 | >0.85   |

According to the criterion of evacuation stability proposed in this paper, the crowd of Shanghai Hongqiao Railway Station is in a stable state, but we can obviously see that the waiting hall is the place where the crowd gathers mostly.

### 6. Conclusion

Under the background of frequent trampling incidents of large-scale crowd, it is particularly important to study the real-time judgment on evacuation stability. For this reason, the large-scale crowd evacuation stability state assessment model was proposed in this paper, based on big data technology. In the process, the crowd thermodynamic distribution map is formed to visually show the degree of crowd density, and also to provide real-time data for crowd stability judgment. According to the real-time density data and the basis of the criterion of crowd stability, the real-time judgment of crowd stability can be realized, which can provide real-time and effective scientific basis for crowd evacuation management and contribute to the prevention of crowd trampling accidents.

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