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Stampede Risk Recognition for Evacuation Study Using Thermodynamic Diagram Remote Sensing

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The evaluation and research on the critical value for tourism crisis will help to greatly improve the accuracy of pre-crisis recognition. This paper takes Shanghai Bund Stampede on 2015 New Year's Eve as an example. It aims to analyze population distribution in different periods by comparing the thermodynamic diagram which has characteristics of describing the population distribution, population density and the changing trend in real time. By combining documented evidence of other accidents, this paper calculated the critical value to determine the occurrence of crowd stampede. There are two main conclusions: (1) According to the data analysis, the population density of the crisis is 5 persons per square meter; (2) the critical point of population density can be calculated by the case data. This paper expects to attract more attention on the tourism crisis warning system, hoping that the negative influence of social crises would greatly reduce.

1. Research background

With the rapid development of China's tourism industry, many resorts are overcrowded by tourists in the peak time of holidays. In this case, if a crisis occurs, and at the same time there is no decent emergency plan, it would cause irreversible harm to tourists. The property damage and social impact is difficult to assess. However, from a practical point of view, one of the priority foundations of establishing and improving a safety pre-warning system for tourism is to be able to accurately determine the occurrence of pre-crisis.

In other words, a timely forecast of an impending crisis is the most important starting point of whether the safety warning system starts or not. However, if there is no judgment basis of scientific crisis's occurrence, then the qualitative judgments on the likelihood of the various crises would be lack of an accurate estimate standard. The early warning system will start slowly, and it will lose the best rescue time.

This paper intends to analyze and verify the critical value of the population density which determines the crisis of tourism. It takes Shanghai Bund Stampede Accident on 2015 New Year's Eve as an example; it aims to analyze population distribution in different periods by comparing the thermodynamic diagram which has characteristics of descripting population distribution, population density and the changing trend in real time. By combining documented evidence of other accidents, consulting researches other scholars have made and then comparing them, we could deduce the population density in the unit area before and after the crisis. This deduction could be the critical value of the occurrence of crowd stampede and the determining basis of crisis's occurrence. It will provide a foundation for the late-depth research.

2. Preliminary studies

The critical value of population density crisis has a direct and close relationship with the judgment of crisis's occurrence. (Guttentag, 2009; Balestrin, 2015) pointed out that once the population density exceeds the critical value, the people would be at great risk. When the population density exceeds 5 persons per square meter, it could be regarded as a continuous medium. (Antonio, 2015; Feng, 2011; Miyoshi, 2011; Yaofang, 2011; Ren, 2005; Ehsan, 2016; Zhang, 2012; Olson, 2009) and others mentioned in the study: For a stationary crowd, the secure critical density is 4.7 persons per square meter; and for the moving crowd, the secure critical density is 4 persons per square meter. (Steven, 2010; Zeitoun, 2010; Steven, 2010; Pel, 2012;

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Zhang, 2012; Wang, 2006; Andrews, 2010; Rall, 2005) calculated that the crowd density should be 0.54 to 3.8 persons per square meter. Individuals can move relatively freely at a value of 0.54 persons per square meter or less. While the value reaches 3.8 persons per square meter or more, it will be likely to cause serious congestion. In terms of information exchange in the crowd, Pauls had pointed out that bund stampede often occurs before and after the failure of information exchange in the crowd.
The previous studies showed that Using Thermodynamic Diagram Remote Sensing could offer the reasonable and effective collecting resources that this study is aiming to use this method to select the sufficient information for analyzing the population distribution process.

3. The background of Shanghai bund stampede accident case

3.1 The introduction of the site of Shanghai Bund accident

Shanghai, located at 120° 52' E to 122° 12' E and 30° 40' N to 31° 53' N, is a historical and cultural city of China which has rich mineral and biological natural resource. It has attracted many domestic and foreign tourists, especially the most famous place, Shanghai Bund. As a public area, Shanghai Bund Scenic Area covers an area of about 3.1 square kilometres. Chen Yi Square, the site of the accident, is located in the central area of Bund (across the road of Zhongshan Dongyi Road No. 335 to No. 309). The public area of Chen Yi Square is 2877 square meters. Chen Yi Square is connected with Huangpu River sightseeing platform by a large staircase and a wide ramp.

3.2 Introduction of Shanghai bund stampede accident

The accident happened in the walkway stairs in the southeast corner of Chen Yi Square which leads to the Huangpu River sightseeing platform. The ladder has two sets of 17 stairs in total and the space between two steps sets is 2.3 meters. On both sides of the stair, there are stainless steel handrails. The stair width is 6.2 m. The maximum height of it is 3.5 meters from the ground and its depth is 8.4 meters. It covers a public area of about 2,877 square meters. At 22:37 of that accident night, after the one-way traffic warning tape of the walkway stair in the southeast corner of Chen Yi Square leading to the Huangpu River sightseeing platform was broken, a lot of tourists swarmed to the sightseeing platform conversely. From 23:23 to 23:33, the up and down people flowed constantly and became a stalemate, and then formed a "surge." At 23:35, the downward pressure of the crowd increased sharply, resulting people in the bottom of the ladder lost their balance and fell down. Later, more people fell down and stacked. Therefore, the crowded stampede occurred, resulting in 36 deaths and 49 people injured.

4. The data analysis of the population density based on of thermodynamic diagram

4.1 Comparison of the population density data between the day of the accident and the day before

According to the monitoring and reporting of the population flow in Bund, at 20:20, the population flow in the sightseeing platform is 5 persons per square meter. At 21: 14, the population flow was 5 persons per square meter. At 21: 39, the population flow was 6-7 persons per square meter. At 22: 45, the population flow was 5-6 persons per square meter. When Shanghai Bund was designed, the planners calculated that the population capacity in the usual peak day (non-extreme peak) is 400,000 people in accordance with the data of 1 person per square meter at peak periods. According to statistics, at normal weekends, the population flow is about 60,000. And on holidays, it reaches almost 90,000. However, it reached about 150,000 on 2015 New Year's Eve. On December 30 and December 31, 2014, the thermodynamic diagram contrast of population density which was generated by mobile phones at the site of the accident (Figure 1) shows that the red represents the densely crowded and the orange follows. The degree of crowds' aggregation increased significantly. Figure 1 is the thermodynamic diagram contrast of population density at that night of the accident and the day before at the same time. The figure shows that the population density is relatively balanced in the evening of Dec. 30, 2014. On that night, apparently both the population density and the population distribution changed dramatically before and after the accident.

4.2 The analysis of the population density per unit area when the incident occurred

At 20:00 of the incident, the number of people entering the Bund Scenic Area exceeded the number of people leaving it. A large number of visitors flocked to the Bund sightseeing platform which had a trend of crowd aggregation. The comprehensive test shows that the population flow in Bund Scenic Area was about 120,000 from 20:00 to 21:00, 160,000 from 21:00 to 22:00, 240,000 from 22:00 to 23:00 and 310,000 from 23:00 to the time the accident happened.
According to the proportion of the area where the accident occurred and the population flow on the Bund, we can estimate the population density of when (24:00) and where the accident occurred. When the accident occurred (24:00), the population flow of Chen Yi Square was as follows:

The area of Chen Yi Square ÷ the total area of the Bund × the total number of people in the Bund when the accident occurred = the total number of people in Chen Yi Square

$$2877\text{m}^2 \div (3.1\times106)\ \text{m}^2 \times 310000 \text{ persons} = 287.7 \text{ persons} \quad (1)$$

Before the accident, the crowds flocked to the sightseeing platform and they gathered at the ladder and the sightseeing platform. The population density at that time reaches (The total number of people in the Bund when the accident occurred ÷ the area of accident site = population density per square meter):

$$287.7 \text{ persons} \div (6.2 \times 8.4)\ \text{m}^2 \approx 5.5 \text{ persons} / \text{m}^2 \quad (2)$$

The population density already reached 5.5 persons per square meter when the accident occurred. It indicates that there is a big risk of accidents before reaching this density. It can be inferred that the critical value of secure population density must be less than 5.5 persons per square meter.

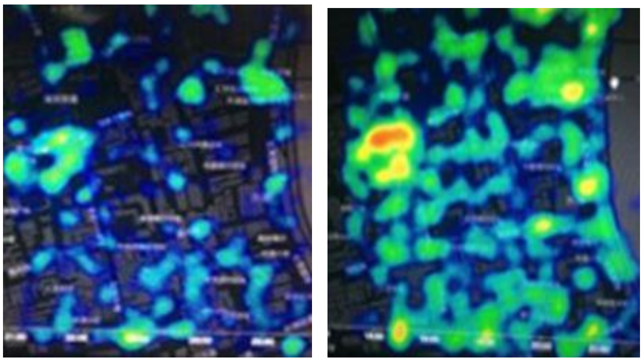
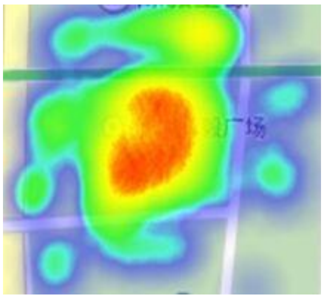


Figure 1: The thermodynamic diagram contrast of the Bund (the left is the evening of Dec. 30, 2014; the right is the evening of Dec. 31, 2014, 1-2 days before the accident-happened night)

4.3 The thermodynamic data analysis during the accident

In order to reflect the changes of the population density before and after the accident, this paper analyzed and compared the thermodynamic diagram data of population density in Chen Yi Square within two hours before and after the accident at 15-minute intervals. (Figure 2-- Figure 9).



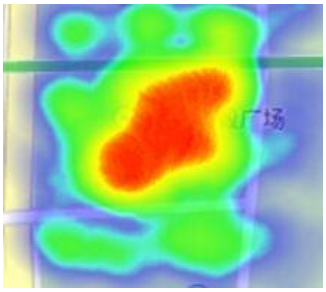


Figure 2: 23:00-23:15 *Figure 3: 23:15-23:30*
(The population density in Chen Yi Square)

Figure 2 is the distribution of the crowd half an hour before the accident. Referring to the color in the thermodynamic diagram and the corresponding population density value, it is clear for us that the degree of population aggregation at the moment was very high. From the color it can be inferred that most of the central area was yellow and light red. It indicated the population density was close to 5 persons per square meter at that moment. Figure 3 shows the time directly close to the stampede accident; it had the similar population distribution area with the one during the accident. At 23: 15-23: 30, just few minutes before the accident, the central red area is more focused and the color is deeper, the highest population density reached to 4 to 6 persons per square meter. The surrounding color is mostly dark green and its density is 2.5 persons per square meter.

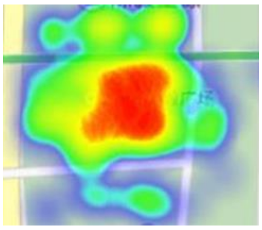
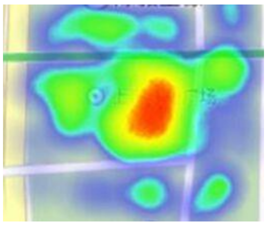
 

Figure 4: 23:30-23:45 *Figure 5: 23:45-00:00*
(The population density in Chen Yi Square)

Figure 4 represents the thermodynamic diagram within a short time after the stampede accident happened. The figure shows that, population distribution reached the most congested state until accident happened. At the very moment of the accident, population density reached the highest point and the confusion reached the highest level, population density then is around 5 to 7.5 persons per square meter. In the following few minutes, the crowd was evacuated, but the effect is still not clear. The crowd was still under risk. Apart from the red color section, most of other areas are still in a more secure and stable state, the density there varied within 2 to 4 persons per square meter. Figure 5 is the population distribution state within a quarter of an hour after the accident. Accident occurred around that time, therefore tourists had the sense of risk aversion, the crowd had a relative loose and the scope of distribution area gradually narrowed. However, there are still some orange areas. The population density then was about 4 persons per square meter. The crowed areas are mostly green and the density is about 2.5 persons per square meter. The possible reason is that during the accident there was not enough time left to escape, consequently the crowd couldn't reach a completely safe condition.

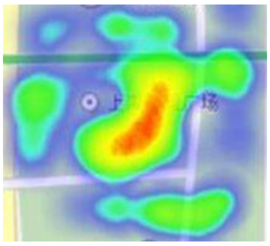
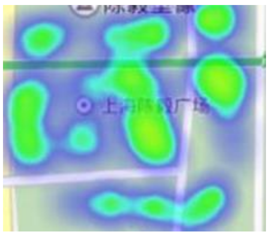
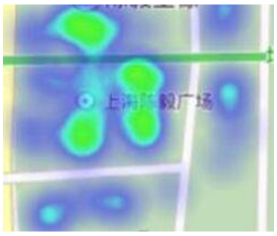
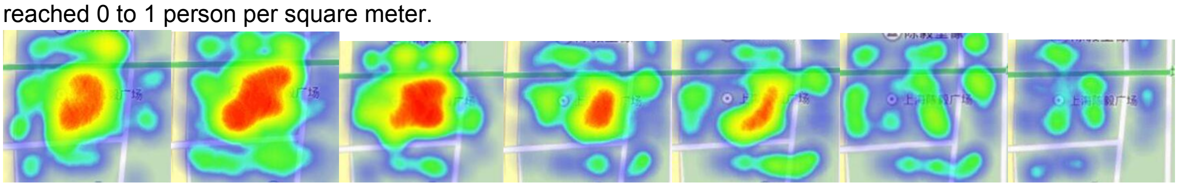
  

Figure 6: 00:00-00:15 *Figure 7: 00:15-00:30* *Figure 8: 00:00-00:45*
(The population density in Chen Yi Square)

Figure 6 shows the state within half an hour after the accident. Relatively speaking, the population density had a great decrease and the distribution area also shrank greatly, however, the maximum density is still in the orange zone. As there still were some people unaware of the danger in the accident area or were observing at the time, the population density was 3.5 to 4.1 per square meter. Figure 7 is displaying the morning after the accident. The risk had significantly reduced and the red zone basically disappeared, population distribution was scattered and the scope decreased obviously. It means that the risk of population density at this time had been basically removed, the majority of staff had been evacuated, and even some areas had reached the empty state. Nevertheless, the density did not reach the most secure point. Thermodynamic diagram still has deep green color in areas where the crowd was located. The population density there is 3 persons per square meter. Figure 8 starts from 00:30, the crowd then was greatly loosened and already distributed as sporadic or dot-shaped with lighter color. There is also a large number of blue zones in population accumulation area, which shows that the population density in this case is 2 to 3 persons per square meter, even large zone has reached 0 to 1 person per square meter.



23:00-23:15 23:15-23:30 23:30-23:45 23:45-00:00 23:30-23:45 23:45-00:00 00:00-00:45
Figure 9: Thermodynamic diagram contrast of population distribution during 23:00 to 01:00 in next day

In regard to Figure 9 where the population distribution within two hours after the accident is displayed, we can conclude that the most intensive area is always in the periphery of the accident site. Moreover, people gathered increasingly and red area expanded gradually with deeper color before the danger, indicating that population density was also increasing. In addition to the red area, the crowd in green and orange areas was also increasing. But after the danger, the scope of red area obviously narrowed and the color saturation also decreased accordingly, while other areas gradually weakened as a lighter green color indicates. The overall population distribution varied from the large-scale gathering to small-scale scattering state, and the size of density showed an increase-decrease parabolic trend. The final result of population density approached or equals zero.

4.4 Data Discussion

The foregoing analysis of the whole stampede process shows that although population density reached 7 persons per square meter, it was the chaos that led to this result, indicating the population density in the case of danger is no more than 7 persons per square meter. According to thermodynamic diagram, the density was 4 to 6 persons per square meter when in danger; we take the median value of 5 persons as a threshold to judge crises. This critical value is basically consistent with the 5 pointed out by Tong Ruipeng, 4.7 regarded as safety critical density by Liu Mao and others, and -3.8 calculated by Nelson and Maclennan. Therefore, through this study, it is reasonable to infer threshold of population density is 5 persons per square meter when in danger.

5. Conclusion

It has been seen from previous studies that critical value of population density can be estimated by data in cases. This paper refers to population density data of the Shanghai Bund accident, and applies it to the determination of Tourism Crisis, but also contributed to tourism crisis early warning mechanism. It can further determine a more specific population density when in danger. In this paper, the combination of thermodynamic diagram and actual population makes the results more convincing. The results not only provide a density threshold to determine tourism crisis, but are also referred to the closed crowd density threshold, based on which can be further applied to the population density of a indoor scenic spot, and even can be used as a reference to determine the occurrence of other types of tourism crisis.

6. Prospects

Through this study, a security value is concluded for tourism pre-crisis recognition from the perspective of population density. On this basis, follow-up research can also be a more in-depth study. The results obtained in this paper can be further used as the population density threshold to determine Tourism Crisis. However, due to the limited time and manpower, the study doesn’t extend to the outside of the Bund or other scenic attractions. In follow-up studies, we will not only be limited to the conclusion of population density threshold, we will provide reliable early warning indicators for tourism pre-crisis. Based on the conclusion of population density threshold, future study can combine thermodynamic diagram, population statistics, photo show or visitors interview, as well as get real-time thermodynamic diagram of population density by imitating existing scientific software technology. The conclusion of this study made 5 persons as a threshold to judge crises. But it must realize that according to the different environment factors, the situation would changed a lot. So, in the future studies, this study is going make further research on different level crises judgment based on different environment and other factors. As one of the limitations to the paper, it was using mobile phones data to evaluate the stampede risk recognition that it might not be very accurate. Because many of the people on the Bund were foreigners possibly without Chinese sim-cards, and those people’s phones were possibly turned off. So there might be further research papers on how to improve ways of monitoring crowd levels by cellphones to avoid the stampedes. This paper aims to attract whole society’s attention to studying tourism pre-crisis warning mechanisms, as well as to optimize governments methods of disaster reduction in hazardous incidents with modern network technology, thus greatly reducing all kinds of negative influence to society caused by emergency incidents. For the future study, how to get the real time distribution of population density in the site is one of the major subject.

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