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Safety Forecasting and Early Warning of Highly Aggregated Tourist Crowds in China

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ABSTRACT With tourism development in China, the influx of tourists in popular tourist attractions has become more frequent. However, space cannot accommodate such a large influx of tourists. Through empirical testing, this research identified 23 variables that influence the safety of tourists in crowded spaces. We divided 23 variables into three factors: pressure factors, state factors, and crowd management actions. Based on the data collected, this study proposes a system model that includes a feedback mechanism to evaluate the safety of highly aggregated tourist crowds (HATCs) and identify moments requiring security warnings. System simulation results showed that the safety level of HATCs presented a complex process of change in different situations. Thus, management can take corrective actions. We tested this model by simulating different crowding conditions and assessing the safety level of tourists. Different warning plans were proposed based on the simulated security level.

INDEX TERMS Highly aggregated tourist crowds, safety evaluated, status simulation, early warning, system dynamics.

I. INTRODUCTION

We are entering a crowded era [1] in which crowding frequently appears [2]. The high density and complexity of a crowd can put tremendous pressure and the threat to its members [3], [4]. Therefore, emergencies occur more easily in crowds [5], including trampling accidents [6], injuries, and deaths [7]. However, supervising the crowd and guaranteeing its safety is a difficult and important task for the organizers [8]. Therefore, exploring and strengthening crowd safety is a very urgent research topic. Various crowd phenomena exist [9], including protest demonstrations [10], crowding [11], sports crowds [12], religious crowds [13], mass gatherings at festivals [4], [5], [14], [15], and highly aggregated tourist crowds [16]–[20]. Different types of crowd exhibit different types of behavior [21]. The safety issue of crowds is essential, but if we do not distinguish between the crowd types for management, it can lead to random crowd management, and then generate disaster [22]. Therefore, it is necessary to explore the safety issues of specific crowd types to develop effective management.

Among the types of crowds, the highly aggregated tourist crowd (HATC) is special. The HATC is a unique dense crowd with more than 50 tourists and more than 2.0 persons/m^2 in the special space [18]–[20]. Crowd safety is an important research topic that has received much attention [23], [24]. Many studies have focused on investigating the densities of crowds [23], [25], [26] and analyzing their different behaviors. These behaviors include evacuation behavior [27] and crowd behavior under panic conditions [28]. However, research on the safety issues of HATCs is few. And on the research of the HATCs, many studies have focused on the factors affecting HATCs [18], [19] and safety management strategies [29]–[31]. The premise and basis of safety management strategies of HATCs are to figure out how HATCs change and their contribution to changes in safety status. However, forecasting safety statuses and formulating early warning projects for HATCs lacks a systematic investigation. In addition, when issuing a warning message and which warning level should be implemented are unclear.

Differentiating crowds types and exploring special behaviors of crowds types is the basis of crowd management [22]. Due to the significance and urgency of HATCs safety issue, this paper aims to shed light on this special group and explore

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the safety issues related to it. In detail, this paper has three objectives.

1. The primary purpose of this paper is to explore and figure out the operating mechanism of HATCs. Just the crowd is a living system [32], so is the HATC. Determining the operating mechanisms of HATCs is useful and is also the antecedent for crowds' safety management. Before assessing and forecasting the safety status of HATCs, it is necessary to determine how the system operates.

2. This paper aims to address the question of how to gauge the safety statuses of HATCs under different conditions. Assessing the safety of dense crowds can be treated as a future research direction [33]. If we want to manage HATCs effectively, we need to clarify the safety status of HATCs. Simulation forms the premise of safety assessment and forecast [34]. Therefore, this paper simulates the changes to HATCs before assessing and forecasting safety statuses.

3. After assessing and forecasting the safety status of HATCs, we want to figure out the gradations of early warning level time nodes and when to release early-warning information.

The remainder of this paper is organized as follows: The literature section summarizes the extant literature on safety issues of tourists, crowds, and HATCs. The research design section introduces the basic theory, research data, and analysis method used in this paper. The results section contains the results of data analysis, including revealing the operating mechanisms of HATCs, assessing the safety of HATCs, and proposing early warning plans for HATCs under different conditions. The last section concludes the paper and includes a summary of the main findings. It puts forward the contributions, limitations, and suggestions for further research.

II. LITERATURE REVIEW

A. THE SAFETY AND SECURITY OF TOURISTS

With the popularity of tourism, the safety and security of tourists is an important and global issue [35]. At first, research has focused on crimes related to tourism [36]. With this development, there emerged many different types of tourists, such as adventure travelers, global travelers, female tourists, self-driving tourists, backpackers, and so on. As the security of tourists became more important, many papers gradually focused on the safety of these different types of tourists. Primarily, senior tourists' safety and security have received much attention [37]. Then, casual sex and the risks of HIV of young female tourists also received attention [38]. Tourists, especially foreign travelers and backpackers [39], are at increased risk of contracting sexually transmitted infections [40], [41]. What is worse are alcohol-related assaults and sexual assaults [42]–[44] on backpackers. Thus, many studies have focused on risk perceptions and risk reduction strategies [45]. At the same time, more and more studies have begun to focus on the safety issues of self-driving tourists [46], such as their safety concerns [47] and safety perceptions [48]. However, with the development of tourism, popular destinations, city centers, and tourism facilities attract large numbers of tourists that give rise to crowding phenomena [49], [50]. A large number of tourists gather in specific spaces at the same time and form highly aggregated tourist crowds. It is a pity that although there are studies that pay attention to the safety issues of adventure travelers, global travelers, female tourists, self-driving tourists, and backpackers, there is little research that focuses specifically on the safety issues of this special type of tourism.

B. CROWD SAFETY

Crowd safety is an important research topic that has received much attention [23], [24]. These studies on the safety of crowds can be treated as the basis for this study on the safety of HATCs. Many studies focus on the influencing factors that affect the safety of a crowd. Specifically, these studies focus on two main topics, namely crowd density and crowd behavior.

Crowd density is often measured by the number of people gathered in a unit area. The higher the density is, the more people gathered in a unit area, the more complex the behavior of people is, the harder it is to control. Simply, crowd density is the root cause of many accidents [51]. With the appearance of increased crowding in a crowd, the normal order of the crowd will gradually decrease [52]. The higher the density of the crowd is, the higher the potential risk of accidents will be [26], [53]. A density higher than three to four persons per square meter for large crowds should be avoided [25]. Zhan *et al.* (2008) [2] argued that the density of the crowd should be controlled to be below five persons per square meter. Therefore, many researchers regard five persons per square meter as the critical density [23], [26]. If the density of a crowd is higher than this, it is not only dangerous for the crowd but also more likely to cause disaster. Therefore, scholars have spent efforts focusing on estimating the density of crowds. Many methods estimate the density of crowds, such as using a wearable electronic device that can detect density [23].

However, the complex behavior of crowds has been another root cause of accidents [33]. Many researchers have suggested using video cameras to monitor the complex behavior of crowds [13], [54]. For instance, the indicator entropy has been used to evaluate crowd mutations that have caused disasters in crowds [55]. Notably, crowd simulation is also widely used to study pedestrian behaviors. Many studies have used the simulations to analyze crowd behaviors, such as the simulation of crowd behavior under panic conditions [28], simulation of crowds' evacuations [27], and the simulation of crowds' behavior at T-junctions [56].

C. SAFETY OF HATCs

Crowding got much attention since it is a general phenomenon in tourism. Thus, many studies focused on the crowding ocurring at different places, such as at urban heritage sites [57], in protected areas [58]. In addition, the crowding of tourists had many negative effects on satisfaction [59], traveler identification [60], disturbance of visitors [58] and the sustainability of tourism [61]. To be noticed, HATCs are a specific type of crowd phenomena. With the normalization and popularization of tourism, HATCs have appeared increasingly frequently [17]. However, research on their safety is still in its infancy. Few previous studies have begun to explore the safety of HATCs. Nature, environment, facilities, management, space-time, and other factors can affect the safety of HATCs [18], [19]. In addition, some studies have focused on the management of HATC safety by studying strategies such as congestion mitigation [29], the dynamic adjustment of traveling routes [30], and emergency evacuation [31]. However, research on this topic has not received adequate attention. Besides, the safety issues of HATCs should be paid enough attention to dynamically evaluate the safety status changes of HATCs.

III. RESEARCH DESIGN

A. DATA SOURCES

The number of domestic tourists in China is very large. In 2018, China had 5 billion domestic tourists. Because of the holiday system in China, tourists often gather together at certain tourist attractions at the same time. Under the catalyst of special time nodes, the HATCs are likely to appear at specific sites. For example, during China's National Day (The National Day holiday runs from October 1st to October 7th), the cable car stations, transfer centers, and ticket windows are always crowded. These areas often have massive crowds and form HATCs (FIGURE 1). With the normalization and popularization of tourism, HATCs began to appear more and more frequently. China faces enormous challenges in effectively managing these crowds and ensuring crowd safety [33]. Thus, this paper focused on the urgent problem, safety issues of HATCs and conducted research in China.

FIGURE 1. **Highly aggregated tourist crowds (HATCs) Note: Pictures were retrieved from http://dy.163.com/v2/article/detail/CU24SN7A0524H6TV.html.**

1) QUALITATIVE DATA: CASES

Analyzing typical cases is an important path to researching the safety of HATCs. This paper used Baidu News and Sina Weibo to search for typical cases on the safety of HATCs for the following reasons: Baidu News is the largest Chinese news platform launched by China's largest search engine, Baidu [62]–[64], which can ensure the collection of a sufficient number of cases. Baidu News has retained all news events since July 2003, ensuring that we can collect enough information. In addition, Sina Weibo is the most popular microblogging service in China with a total number of users that is close to the number of Twitter users [65]. Sina Weibo records what people see, hear, or experience in the self-organized platform and provides a platform for data mining [66].

We used ten kinds of keywords, such as 'Scenic + congestion' and 'Tourists + blowout' to search for and collect the cases. In addition, this paper proposed five principles of case selection. First, the time period for the cases that were collected from Baidu News ranges from November 4, 2003 (Baidu News was launched on November 4, 2003) to May 31, 2017. Meanwhile, this paper collected cases from Sina Weibo from August 14, 2009 (the day when Sina Weibo was launched) to May 31, 2017. Second, we localized the cases in mainland China, including 22 provinces, 4 municipalities, and 5 autonomous regions. Third, the cases that were collected from Baidu News were taken from the online version of published, local government official websites, professional news sites, and authoritative websites (including mainstream social media and websites in China, such as China's mainstream media: Sina, Sohu, NetEase, www.toutiao.com, www.gmw.cn, people.cn, ifeng.com, etc.). Fourth, the cases that were collected from Baidu News and Sina Weibo were required to be accompanied by pictures or videos, which can help us to intuitively determine whether the case falls within the HATC categories based on the visual information. In this paper, we treated the crowds whose density was higher than 3 persons per square meter and where more than 50 people were gathered together as HATCs. HATCs were mainly identified and defined according to two patterns. In this paper, whether a crowd was a HATC or not was judged mainly based on whether the news directly mentioned the density and population of the crowd. The second estimates whether the number and density of the crowd met the HATC standard according to the scene's pictures and video. Fifth, the text of the collected cases was required to be more than 200 words, which can ensure that the cases contain enough information. According to the above principles, this study collected 264 cases. Among these 264 cases, 158 cases came from Baidu News, and 106 cases originated from Sina Weibo. Our data collection method complied with the terms and conditions for the websites from which we collected data (Sina Weibo and Baidu News). Besides, all the personal information of tourists involved in the cases is protected.

2) QUESTIONNAIRE DATA

According to our analysis of the cases, there were 26 factors that influenced the safety of HATCs (Specific to see the section Case study: Preliminary extraction of influencing factors of safety of HATCs). These factors were combined into three categories: pressure factors, state factors, and management factors. Then, we used a questionnaire to collect the perceptions of tourists in HATCs to empirically test these factors with exploratory factor analysis (EFA). These 264 cases collected from network in this study involved different spatial types. From a macro perspective, the accidents took place in multiple scenarios, including mountainous places (56.44%), traditional cultural areas (8.71%), historical places and sites (7.20%), rivers and lakes attraction (6.44%), theme parks (4.55%), ancient monuments (4.17%), coastal island attractions (3.79%), public areas (3.03%), ancient sites (3.03%), classical gardens (1.14%), natural landscapes (1.14%), other places (0.38%) and other places than these 12 classes. It is obvious that HATCs easily appeared at famous mountain sites. Thus, this paper limited its study areas of mountainous places and surveyed a typical mountain site, Wuyi Mountain.

This paper used site investigation methods to collect questionnaires during the National Day of China at Wuyi Mountain. During this period, there were 228,100 tourists at Wuyi Mountain. There was an average of 28,513 visitors, which was close to the daily maximum reception volume of Wuyi Mountain. Thus, HATCs naturally appeared at Wuyi Mountain. A total of 300 questionnaires were sent to Wuyi Mountain, and 281 questionnaires were collected with a 93.67% recovery rate and an 88.67% effectiveness rate.

B. METHOD

1) SYSTEM DYNAMICS

A crowd is a living system [67]. Furthermore, the root cause of crowd accidents lies in the failures of the system [68]. Thus, we can analyze the accidents of HATCs from a systemic perspective. The occurrence of accidents of HATCs is the result of the interactions between multiple factors [20]. Therefore, it is an important premise to clarify the interaction of various influencing factors to evaluate the safety of HATCs.

System dynamics (SD) is a system analysis method that was founded by Jay Forrester in industry dynamics management [69]. SD is grounded on the theory of nonlinear dynamics and feedback control and combines the knowledge of other social sciences, such as economics and social psychology to analyze the complex behaviors of systems [70]. SD is a useful methodology to analyze complex systems and behaviors with techniques such as influence and causal loop diagrams and computer simulations [69], [71], [72]. The causal loop modeling of SD focuses specifically on feedback among variables in a system [71], [73]–[75], which can effectively explore the interactions between various factors and determine the causal relationship among the elements [76], [77]. SD is known for its ability to unravel complexity [71] and explore the interactions among the various factors. What is more, SD can also simulate the dynamic changes of a system, evaluate its safety [70]–[72], [75], [78], and formulate an early warning[79].

In the past, many studies usually constructed evaluation index systems to evaluate the research object. However, traditional evaluation methods ignore the interaction between the indicators, and cannot achieve the simulation and prediction of research objects. Thus, this study used SD to figure out how the factors affecting the safety of HATCs interact with one other. Furthermore, this paper collected data from the questionnaire to make a simulation of the changes in HATC systems and dynamically analyzed the safety status. Finally, we formulate an early warning plan for HATCs.

2) COUPLING ANALYSIS

HATC is a dynamic system composed of the pressure subsystem, the state subsystem and the response subsystem [80]. The root cause of crowd accidents lies in the failures of the system [68]. Based on this, the safety of HATCs is affected by the operation effect of the system. However, the safety of the whole system is affected by the interaction between the three subsystems [20]. Therefore, this paper used a coupling analysis to assess the safety of HATCs.

The coupling means that two or more systems affect each other through various interactions. The coupling degree refers to the degree of the system or elements interacting with one other [81]. The coupling degree is used to measure the degree of harmony between the systems by reflecting the trend of the system from disorder to order [81], [82]. The coupling degree of coordination can reflect whether two or more systems promote one other. The root cause of accidents in a crowd lies in the failure of the system [68]. If the coupling degree of coordination in a system is bad, it means that the system faces high risk and is dangerous. A crowd is a living system, as is a HATC [67]. Therefore, this paper used a coupling analysis to assess the coupling degree of HATCs subsystems, which can be regarded as the safety level. This study not only utilized the principle of multi-system coupling coordination in synergetic theory but also constructed the multiple-system coupling coordination function on the basis of the coupling degree model, which was calculated by equation (1).

$$D=(C\times \mathrm{T})^{1/2},\quad \mathrm{T}=a_1\times \mathrm{t}_1+a_2\times \mathrm{t}_2\cdots+a_m\times \mathrm{t}_m \tag{1}$$

where t_1, t_2, and t_m represent each system of coordinated coupling model and a_1, a_2, and a_m refer to the weight of each system, respectively. D refers to the coordination coupling degree and C is the degree of coupling. C could be calculated through equation (2). In equation (2), m refers to the number of systems, and in this study m is 3.

$$C=m[(\mathrm{t}_1\times \mathrm{t}_2\times \mathrm{t}_3\ldots\times \mathrm{t}_\mathrm{m})/(\prod_{i\neq j,i,j=1,2\ldots m}(\mathrm{t}_1+\mathrm{t}_2+\cdots \mathrm{t}_\mathrm{m}))]^{1/m} \tag{2}$$

IV. RESULTS

A. THE OPERATING MECHANISM OF HATCs

1) CASE STUDY: PRELIMINARY EXTRACTION OF INFLUENCING FACTORS OF HATCs

This paper comprehensively analyzed cases and refined the factors influencing the safety of HATCs. Subsequently, grounded theory was applied to identify the factors that influence the security of HATCs. The following process was applied. The open coding analysis was performed based on the following logical analytical procedure: Define the Phenomenon, Develop the Concept, and Extract the Category. According to the analysis of the open coding of grounded

TABLE 1. The factors influencing the safety of HATCs.

Factor	Context	Factor	Context
f1	Catalyst of a special time period	f14	Emergency plan response
f2	Insufficient warning for tourists	f15	Management response for tourists
f3	Pressure of tourist gatherings	f16	Advance management response for tourists
f4	Stimulation of attractive elements	f17	Strengthened management response
f5	Pressure produced by tourists	f18	Insufficient management response for tourists
f6	Environmental pressure of traveling	f19	Insufficient joint response
f7	Service pressure	f20	Insufficient management response
f8	Failure of the service's function	f21	Lack of an emergency plan
f9	The psychological status of tourists	f22	Lack of an advanced management response
f10	The physical status of tourists	f23	Lack of a management response for tourists
f11	The state of tourist behavior	f24	Lack of a management response
f12	Tourists' complaints	f25	Proposing solutions
f13	The state of the order of the tourist crowd	f26	Joint response

theory, by defining the phenomenon (the authors found and defined 216 phenomena), conceptualization (according to the 216 phenomena, the authors identified 138 preliminary concepts), standardization (the authors extracted 68 normative concepts by reanalyzing the 138 preliminary concepts) and categorization (the authors concluded 26 influencing factors after combining and reanalyzing the 68 normative concepts), the authors gradually and finally extracted the 26 influencing factors [20], which are shown in TABLE 1.

The results revealed that 26 influencing factors affected the security of HATCs, including the tourist flow pressure, tourist behavior status, and enhanced management response. The application of a typical grounded theory analytical framework, namely, 'causal condition-phenomenon-context- mediating condition-action/interaction strategy-result', revealed that the following three category factors influenced the security of HATCs: pressure factors, state factors, and management factors.

Pressure Factors: Different types of pressure are one of the causes of crowd accidents [3]. According to TABLE1, this paper found that there were many types of pressures that HATCs faced, such as f3 (pressure of tourist gatherings); f6 (environmental pressure of traveling); and f7 (service pressure). These different types of pressures are combined and referred to as multisource pressures. Thus, the first main category is multisource pressure, and it includes f1, f2, f3, f4, f5, f6, and f7.

State Factors: The sudden changes in the state are often associated with crowd accidents [55]. According to the analysis of the HATC accident cases, there were many sudden state changes, such as sudden changes of the service state, sudden changes of the psychological status of tourists, sudden changes of the state of tourist behavior, and so on. Considering the state changes during the accidents, this paper defined the special phenomenon as a state mutation. The state mutation referred to a dramatic and sudden changes of the state, including f8 (failure of the service's function), f9 (the psychological status of tourists), f10 (the physical status of tourists), f11 (the state of tourist behavior), f12 (tourists' complaints), and f13 (the state of the order of the tourist crowd).

Management Factors: However, whether an accident happened or not is directly affected by the quality of the management response of an organization [70], [72]. According to the 264 cases, this paper divided the emergency management responses into three aspects: the lack of an emergency management response, a low-quality emergency management response and a high-quality emergency management response. All of the cases of the lack of an emergency management response, a poor emergency management response and a high-quality emergency management response are concluded based on the statement of the cases. According to the factors affecting the safety of HATCs that are shown in Tab.1, this paper identified low quality emergency management responses by referring to negative emergency responses

TABLE 2. The factors influencing the saefty of HATCs.

Factor	Context	Factor	Context
F1	Environmental pressure	F12	The state of order of tourist crowd
F2	Attraction of travel resources	F13	Complaint of tourists
F3	Catalysis special time node	F14	The physical state of tourists
F4	Pressure produced by tourist gathering	MF2	State mutation
F5	Service pressure	F15	The response of the emergency plan
F6	Pressure produced by tourists	F16	Manage program response
F7	Early warning for tourists	F17	Management response of organizer
F8	Number of tourists	F18	Management response for tourists
MF1	Multi-source pressure	F19	Joint response
F9	The psychological state of tourists	F20	Management response in advance
F10	The state of service function	MF3	Management response
F11	The state of behavior of tourists		

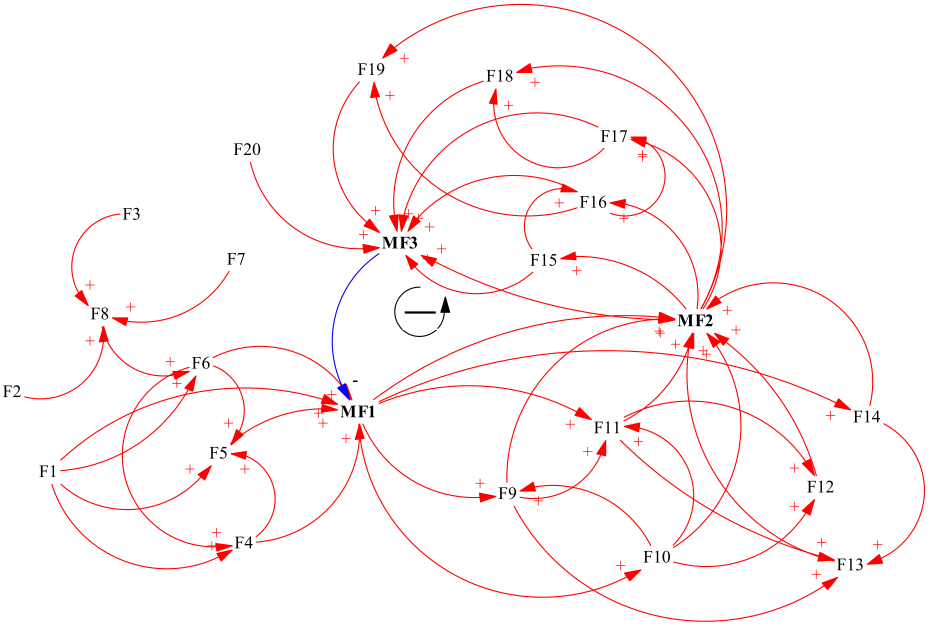


FIGURE 2. Causal loop of a HATC. Note: The arrows refer to the causal relationship between two variables, and "+" and "-" indicate positive and negative causality, respectively. For example, "F8 → + F6" refers to the positive causality between them, which means that F8 positively affects F6.

to multisource pressures and state mutations, including f18 (insufficient management response for tourists), f19 (insufficient joint response) and f20 (insufficient management response [83]). However, high-quality emergency management responses refer to the positive responses of organizations to multisource pressures and state mutation, including f14 (response of the emergency plan), f15 (management response for tourists), f16 (advanced management response for tourists), f17 (strengthened management response), f25 (proposing solutions) and f26 (joint response). When facing multisource pressures and state mutations, if the organization did not conduct any emergency response, we defined it as the lack of an emergency management response, including f21 (lack of an emergency plan), f22 (lack of an advanced management response), f23 (lack of a management response for tourists), and f24 (lack of a management response).

2) QUESTIONNAIRE ANALYSIS: VERIFICATION OF FACTORS INFLUENCING THE SAFETY OF HATCs

According to 26 factors based on the case analysis, this paper designed a questionnaire with 34 questions to collect the perceptions of tourists in HATCs to empirically test these factors with exploratory factor (EFA). According to the EFA, 23 factors (TABLE 2) influence the safety of HATCs. Combining these cases collected from Baidu News and Sina Weibo, this paper analyzed the interactions among the influencing factors with the system dynamics software Vensim 7.0 and proposed the HATC operating mechanism, as shown in FIGURE 2.

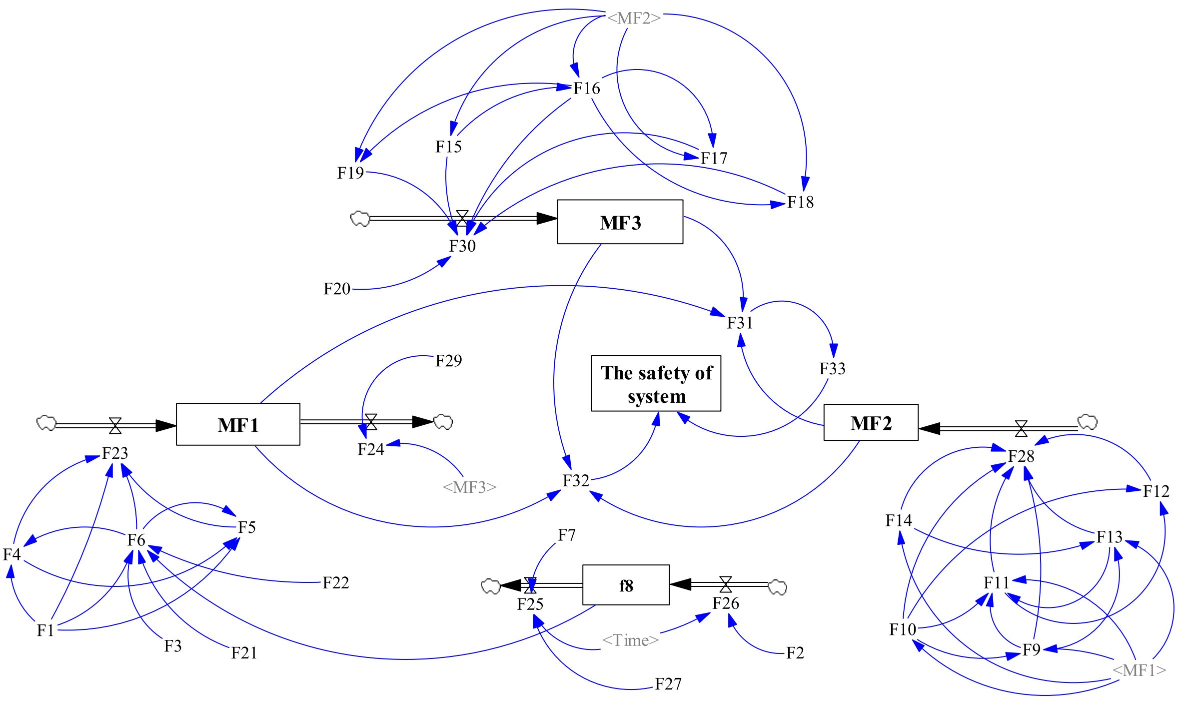


FIGURE 3. A system dynamic model of HATC safety.

We obtained the following information from FIGURE 2:

First, the HATC is a living system that consists of three subsystems, a multi-source pressure subsystem [3], [4] with nine elements, a state mutation subsystem [55] with nine elements, and a management response subsystem with seven elements.

Second, according to the causal feedback loops, the HATC system belongs to a high-order negative feedback system. Negative feedback systems have self-regulating, self-controlling and self-balancing functions. Therefore, the management response subsystem of a HATC would reduce the multi-source pressure and thus maintain the balance of the whole system.

Third, the operating mechanism of the HATCs can be described as follows: under the composite effect of F2, F3, and F7, there is an increase in F6, F5, F4, and F1, which can be combined and named the multi-source pressure (MF1). The MF1 will change the statuses of HATCs such as F9, F11, and F12. These changed states were combined and named the state mutation (MF2). Because of the state mutation of HATCs, the organizer needed to choose a management response such as F18 or F15. In conclusion, the state of the HATC system was affected by the interactions among these three subsystems, namely the multi-source pressure subsystem, the state mutation subsystem, and the management response subsystem. Multi-source pressure results in a state mutation of the HATCs. A management response must then be taken to ease the state mutation.

B. THE SAFETY ASSESSMENT OF HATCs

Safety is a kind of HATC state. The failures of the system in a crowd can result in accidents [68]. Therefore, the state level of a system infers the safety level of a system, to some extent. Because the state of the HATCs was affected by the interactions of the subsystems, this paper assessed the level of interaction effects to estimate the safety level of the HATCs. The assessment process was as follows:

Step 1 Construct the Assessment Model: According to the operating mechanism of HATCs, this paper constructed a dynamic system model of HATC safety, as shown in FIGURE 3. This paper added some auxiliary variable factors (shown in TABLE 3) to clearly explain the safety of the HATCs.

Step 2 Determine the Weight of Each Factor: Before the simulation, it was necessary to determine the functional relationships between the various elements. This paper used the AHP method [84]–[86] and the Entropy method [87], [88] to determine the weight of each subsystem factor. The weights of each factor in AHP were given by two professors versed in tourism management research and one manager of Wuyi Mountain. Additionally, this paper used Entropy method to calculate the weight of factors based on the collected questionnaire information. The average weight obtained from the AHP and Entropy methods was treated as the weight of each factor, as shown in TABLE 4.

Step 3: Determination of each simulation function equation: Based on the weight of each factor, this paper listed the

TABLE 3. Other factors added to the assessment model.

Factor	Context	Factor	Context
F21	Space	F28	The increment of state mutation
F22	Coefficient of conversion of pressure produced by tourists	F29	The decreasing rate of "management-pressure"
F23	The increment of pressure	F30	The increment of management response
F24	The decrement of pressure	F31	System coupling
F25	Outflow	F32	□ System Composite Index
F26	Inflow	F33	The degree of system coupling
F27	Normal outflow rate		

TABLE 4. The weight of each factor influencing HATC safety.

Factor	Context	Weight	Factor	Context	Weight
F12	F11	0.8333		MF1	0.1047
	F10	0.1667	F13	F9	0.2583
F23	F6	0.5538		F14	0.6370
	F5	0.1259	F28	F12	0.3005
	F6	0.0727		F10	0.0448
	F1	0.2477		F9	0.1105
F19	MF2	0.8750		F11	0.3272
	F16	0.1250		F13	0.0845
F18	MF2	0.3333		F14	0.1327
	F16	0.6667	F17	MF2	0.2500
	F6	0.2583		F16	0.7500
F5	F4	0.1047		F19	0.1193
	F1	0.6370		F18	0.3204
F9	F10	0.6667	F30	F15	0.0614
	MF1	0.3333		F17	0.2943
F4	F1	0.5		F16	0.1063
	F6	0.5		F20	0.0983
F11	MF1	0.1031	F16	MF2	0.2500
	F9	0.5258		F15	0.7500
	F13	0.1297		(F8/F21) × F22	0.5936
	F10	0.2414	F6	F1	0.2493
				F3	0.1571

simulation function equation as shown in the appendix. For example, $F12 = 0.833 \times F11 + 0.167 \times F10 +$ the initial value.

Step 4 Setting the basic premise for the simulation: Before the simulation, it was necessary to set the basic premise. In this study, the basic premises were shown as follows: first, the simulation initial time was 1, the ending time was 4, and the simulation unit was "hour"; second, the simulation step was set as 0.0625 hours, which is 3.75 minutes; and third, this paper assumed that the F8 value of Wuyi Mountain could continue increasing.

Step 5 Setting the Safety Level and Early Warning Level of HATCs: We used the simulation method to assess the safety levels of HATCs. This study determined the warning level according to the classification standard of coupling coordination types [89]. If the value of coupling coordination is less than 0.4, the system is in disorder. Therefore, when the safety of a system belonged to the interval (0, 0.4], the safety level of the HATCs was highly dangerous (HD). If the value of coupling coordination is greater than 0.4 and less than 0.7, the system is in the basic coordination state. Thus, this study regarded the value in the interval (0.4, 0.7] as the moderately

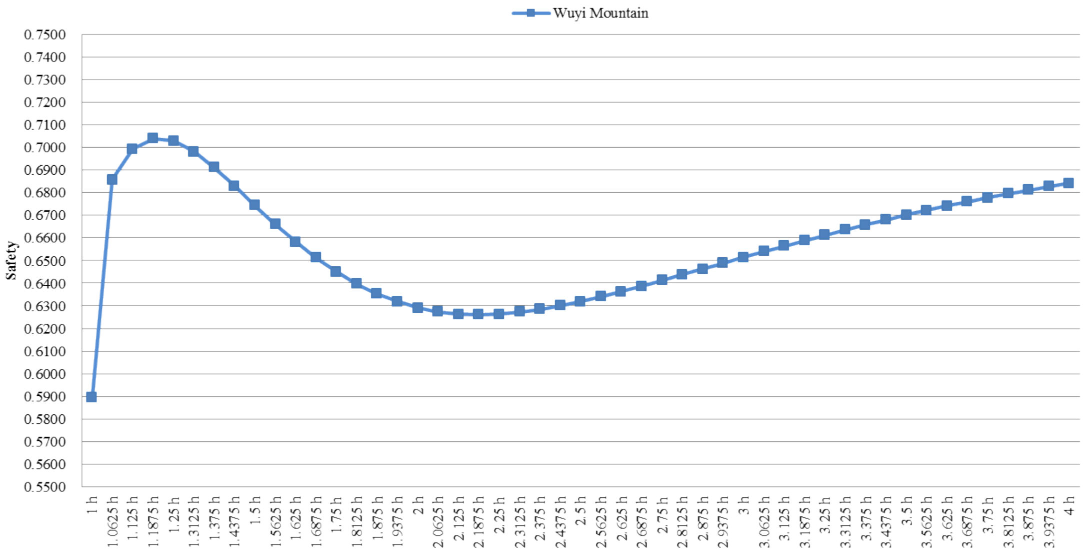


FIGURE 4. **A simulation of the safety levels of the HATC system.**

dangerous (MD). If the value of coupling coordination is greater than 0.7 and less than 0.9, the coordination of the system is not bad. This study treated the value in the interval (0.7, 0.9] as low danger (LD). If the value of coupling coordination is greater than 0.9, it is in superior coordination. In this condition, the state of the system is in slightly dangerous (SD) level.

Step 6 Simulate and Assess the Safety of the HATCs: We regarded the data collected through questionnaires as the initial values and inputted them into the safety assessment model shown in FIGURE 3. The simulation results are shown in FIGURE 4.

Overall, under the initial conditions, the safety levels of the HATCs at Wuyi Mountain were basically in the low danger category (LD). Therefore, it would be necessary to make a slight warning (yellow warning (Y)) for the HATCs' safety levels. According to FIGURE 4, this paper found that there was a significant "increase-decrease-upward" phenomenon in the change of safety. At first, the organization management could completely cope with the pressures and mutations produced by the increasing numbers of tourists. However, with massive growth in the number of tourists, the organization management could not effectively respond to the stresses and mutations. Then, the safety decreased with the decrease of the coupling degree of the crowd. In the end, the organization could strengthen the management response system, which could effectively respond to stress and mutation. Then, the safety of the HATC increased.

C. EARLY WARNING FOR HATCs

Safety assessments and forecasting of HATCs were necessary for early warnings. Therefore, this paper simulated the safety of the HATCs under different situations and proposed different early warning plans for HATCs under different situations. This paper simulated the safety of HATCs at the initial state, the tourist surge state (F26 is three times as much as the initial condition), the tourist-doubled state (F26 is twice as much as the initial condition), and the environment deterioration state (F1 is twice as much as the initial condition). The simulation results are shown in FIGURE 5.

According to FIGURE 5, the safety of the HATC decreased at the deterioration state. Overall, at the tourist surge state, the tourist-doubled state, and the environment deterioration state, the multi-source pressure subsystem changed and decreased the coupling degree obviously between the subsystems. Therefore, under these three situations, the safety of the HATC decreased. Specifically, the effect of decreasing the safety of the tourist surge state was stronger than the environment deterioration state, with an effect that was stronger than the tourist-doubled state. Due to the different effects of different situations and the early warning levels (TABLE 6), this paper proposed different early warning plans (shown in TABLE 6) for HATCs at Wuyi Mountain.

In the short term (from 1h to 1.1875h), there are no differences in the early warning levels under different situations. However, some differences in the periods of early warnings appeared. For example, in the long term (after 1.1875h), there were some differences between the early warning plans. The LD period in the tourist surge state was shorter than that of other periods. However, the MD period was longer than that of other periods. This meant that the safety of HATCs in the tourist surge state was the lowest among the three situations. Also, according to the time distribution of early warning results, the tourist surge state had a more negative effect on the safety of the HATCs than that of the tourist-doubled state, which was more than that of the environmental deterioration state. Hence, the organization should dynamically adjust the early warning plans according to the actual conditions.

TABLE 5. Safety level and early warning level of HATCs.

The safety of the system	Safety level	Early warning level
[0，0.1]-S10	Highly dangerous (HD)	Serious warning: red warning (R)
(0.1，0.2]-S9		
(0.2，0.3]-S8		
(0.3，0.4]-S7		
(0.4，0.5]-S6	Moderately dangerous (MD)	Moderate warning: orange warning (O)
(0.5，0.6]-S5		
(0.6，0.7]-S4	Low danger (LD)	Slight warning: yellow warning (Y)
(0.7，0.8]-S3		
(0.8，0.9]-S2	Slightly dangerous (SD)	Maintain the status (M)
(0.9，1]-S1		

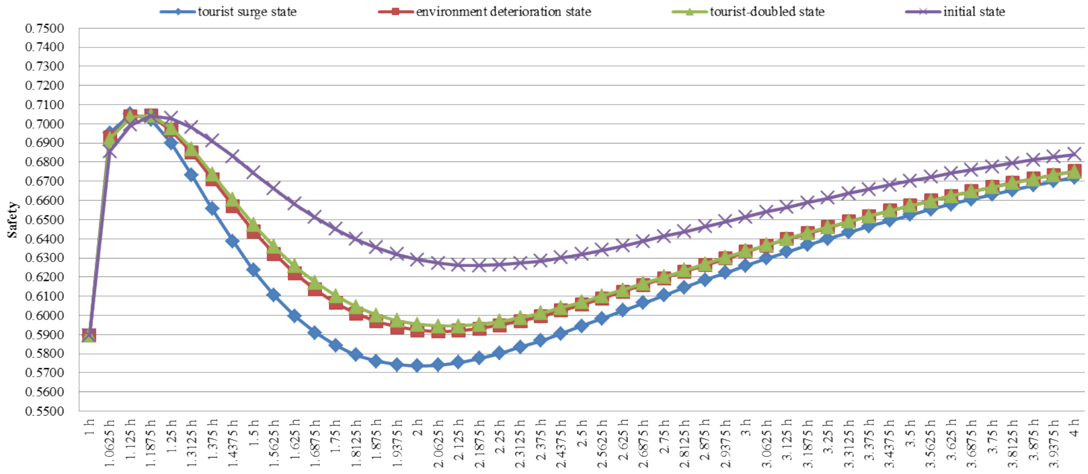


FIGURE 5. The simulation of HATCs safety at Wuyi Mountain under different situations.

TABLE 6. The early warning plans of HATCs at Wuyi Mountain.

Tourist surge state			Tourist-doubled state			environment deterioration state		
Time period (the safety of the system)	Safety level	Early warning level	Time period (the safety of the system)	Safety level	Early warning level	Time period (the safety of the system)	Safety level	Early warning level
1 (S5)	MD	O	1 (S5)	MD	O	1 (S5)	MD	O
1.0625 (S4)	LD	Y	1.0625 (S4)	LD	Y	1.0625 (S4)	LD	Y
1.125-1.1875 (S3)	LD	Y	1.125-1.1875 (S3)	LD	Y	1.125-1.1875 (S3)	LD	Y
1.25-1.5625 (S4)	LD	Y	1.25-1.875 (S4)	LD	Y	1.25-1.8125 (S4)	LD	Y
1.625-2.5625 (S5)	MD	O	1.9375-2.3125 (S5)	MD	O	1.875-2.375 (S5)	MD	O
2.625-4 (S4)	LD	Y	2.375-4 (S4)	LD	Y	2.4375-4 (S4)	LD	Y

V. CONCLUSION AND CONTRIBUTIONS

A. CONCLUSION

This paper employed the system dynamics method to explore the operating mechanisms of HATCs, which are special crowds. This paper collected data and simulated the changes in HATCs safety in different situations. Through the analysis and simulation, this paper found the following:

First, the HATC is a negative feedback system in which the management response subsystem reduces the multi-source subsystem pressure and eases the mutation state subsystem.

Specifically, under the combined effect of the simulation of attracting elements and the catalysis of special time nodes and other influencing factors, multi-source pressure increases. The multi-source pressure can change the state of the HATCs and is identified as a state mutation. After this step, the management response should work to reduce the multi-source pressure and restore the balance of the whole system.

Second, the safety level of HATCs presented a complex process of change in different situations. This paper simulated the safety of HATCs by assessing the coupling level between subsystems. In the initial state, the simulation of the safety of HATCs indicated that a significant ''increase-decrease-upward'' phenomenon appears. Overall, the safety level of the HATCs was at a low danger level. It is necessary to make a slight warning, or yellow warning, to the tourist crowds.

Third, there are different early warning plans under different situations of HATCs. Safety assessment and the safety level forecast of the HATCs were necessary for sending out early warnings. This paper simulated the safety changes of HATCs under the initial state, the tourist surge state, the tourist-doubled state, and the environmental deterioration state. This paper proposed different early warning based on the simulation and safety levels at different times.

B. CONTRIBUTIONS

After exploring the operating mechanisms of HATCs and assessing and simulating the changes in the safety of HATCs, the paper made the following theoretical and practical contributions.

First, this paper revealed the operating mechanisms of HATCs, which can help us figure out the reasons behind the accidents and understand the operation of HATC systems. However, compared with adventure travelers, global travelers, female tourists, self-driving tourists, and backpackers, the safety issues of special tourists have received little attention. This paper regarded HATCs, a special type of crowd, as a research topic and explored the safety issues related to them. In the past, not many studies have focused on the operating mechanisms from a systemic perspective. However, this paper reveals the operating mechanisms of HATC systems, which helps organizers to identify the changes experienced due to these types of crowds.

Second, this paper evaluated the safety statuses of HATCs and simulated the changes in HATCs under different conditions and dynamically evaluated their safety statuses. The results found in this paper are of great significance for enriching and deepening HATC study. Regarding the previous evaluation research, the indexes are often independent of each other, and the influence of the interaction between indexes on the evaluation object is ignored to some extent. With the help of system dynamics methods, this paper focused on the analysis of the interaction between the evaluation indexes and their influence on the security of the HATCs. To a certain extent, this paper solved the immeasurable impact of the interaction between indicators on the evaluation object.

Third, this paper is helpful for effectively managing and controlling the special tourist category, HATCs. While comparing the safety state under different conditions, this paper simulated the changes in the safety of HATCs in the initial state, the tourist surge state, the tourist-doubled state, and the environmental deterioration state, which is beneficial to the organizers to effectively manage HATCs. Additionally, this paper adopted system dynamics simulation methods to solve the problem that management strategy cannot measure the implementation effect in advance, which is helpful to optimize the management strategy. Additionally, this paper simulated the safety state changes of different conditions and proposed different early warning plans for HATCs under different situations, which has important implications for organizers of HATCs. All of these plans can practically help optimize HATC management.

C. LIMITATIONS AND FURTHER RESEARCH

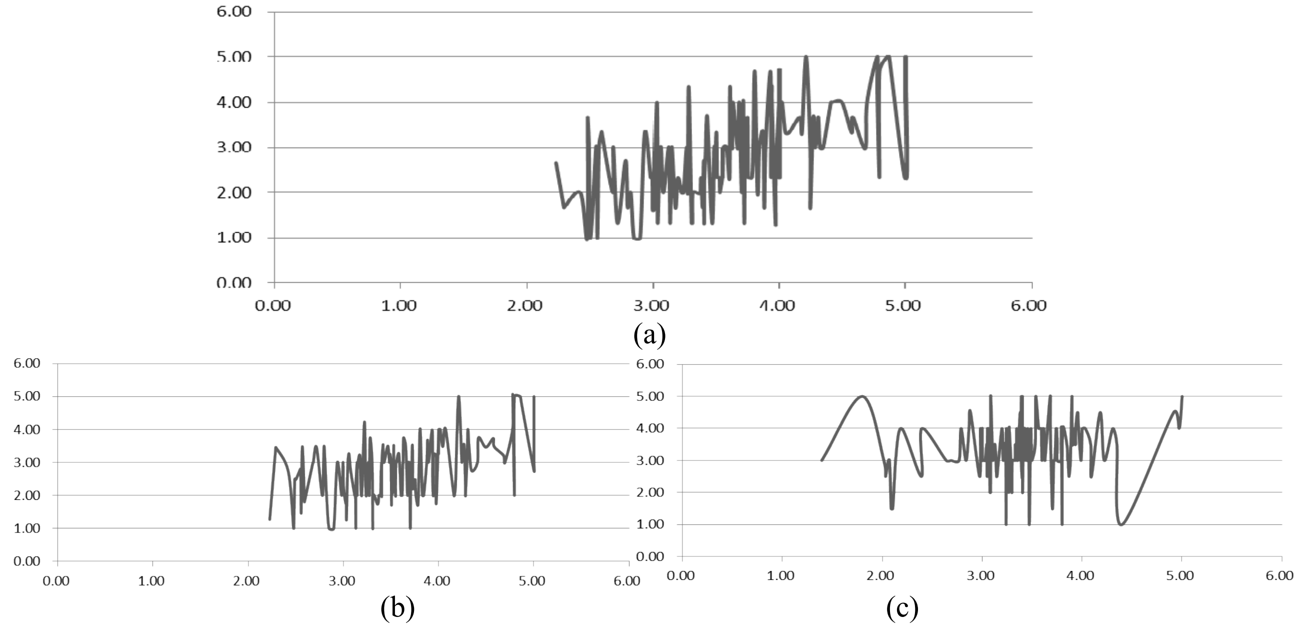
Although this study helps to understand and assess the HATCs, it has some limitations. For example, a clear limitation of this study is that this paper is simulated under relatively ideal conditions and cannot completely simulate or reflect changes in HATCs. Further research is needed to simulate HATCs more accurately. Although this paper assesses the safety of these types of crowds and proposed different early warning plans under different situations, it is necessary to determine how to effectively manage the HATCs and find ways to control and optimize the HATCs. In further research, it is important to explore the impact of simulated HATC management strategies and propose effective management plans in different situations. Finally, this study only investigates a mountainous area in China and ignores the impact of other different spaces on the safety of the HATCs. For instance, HATCs are also common in national parks and theme parks. Indeed, the causes and changes in the theme parks are different from those in the mountains. As such, we should focus on comparing the current status and control strategies of HATCs in different places. Furthermore, we should test the model proposed by this paper in other countries with similar problems in future research.

APPENDIX A
THE QUESTIONNAIRE ON THE FACTORS INFLUENCING THE SAFETY OF HATCs

Tips: According to our analysis of the cases, 26 factors influenced the safety of HATCs. These factors can be combined into three categories: pressure factors, state factors, and management factors. Then, we used a questionnaire to collect the perceptions of tourists in HATCs to empirically test these factors with exploratory factor analysis (EFA). This paper formed the questionnaire with Liker scale (1 means strongly disagree and 5 means strongly agree) according to the 34 factors. The questionnaire was shown as following:

Part I: The perception of pressure factors

1. The site you visited today was attractive to you.



(a)

(b)

(c)

Figure Scatter diagrams of variables

FIGURE 6. (a) Was referred to the scatter diagram of MF1 and F10. (b) Represented the scatter diagram of MF1 and F14. Picture (c) showed the relationship of scatter diagram of state mutation and F15.

2. Presently, tourist numbers in the scenic area are very large.
3. There are tourists' groups with a high concentration in the scenic area.
4. The scenic area is crowded.
5. A group of people remained too long in the scenic area
6. Presently, effective warning measures for tourists have been taken in the scenic area.
7. Situations such as tourists gathering, and congestion are easy to appear.
8. Tourists move sluggishly through areas with poor roads in the scenic area.
9. The current weather conditions may cause inconvenience to the tour.
10. Overall, the tour environment is poor, causing inconvenience to the tour.
11. Presently, the scenic area faces a lot of pressure on the service.

Part II: The perception of state factors

1. Under the current situation, it is easy for tourists to appear unsafe behavior such as conflict, beating, fighting and so on.
2. When tourists flow is large, tourists tend to line up.
3. Presently, highly aggregated tourist crowds are in good order.
4. Presently, the service provided by the scenic area is not timely with lags behind the phenomenon.
5. Presently, there is poor service in the scenic area.
6. Under the current situation, facilities and equipment prone to overload, resulting in failure.
7. Under the current situation, you will be negative, such as appearing irritability, dissatisfaction, disappointment, excitement, resentment, fear and so on.
8. Under the current situation, you will claim the scenic area.
9. Under the current situation, it is easy to be injured.
10. Under the current situation, it is easy to be uncomfortable.
11. Under the current situation, it easily leads to physical illness for tourists.

Part III: The perception of response management factors

1. Presently, effective measures have been taken for tourist management.
2. Psychological response measures have been taken, such as appease tourists' mood.
3. Measures have been taken to strengthen the management response for tourists, such as increasing management staff.
4. The number of site managers to effectively manage tourist groups is enough.
5. Under the current situation, targeted management measures have been taken to deal with the highly aggregated tourist crowds.
6. There is an effective management program for highly aggregated tourist crowds.
7. Once the security issues happen in the scenic area, an orderly response will be formed.

8 . Once the security issues happen in the scenic area, quick and effective will be formed.

9. Measures have been taken to respond to highly aggregated tourist crowds, such as extending service time.
10. Scenic spots joint with other departments (such as the police) to make common management for highly aggregated tourist crowds.
11. Once the security issues happen in the scenic area, scenic spots can coordinate the rescue efforts.
12. Once the security issues happen in the scenic area, external rescue forces can quickly reach the area.

APPENDIX B
THE FUNCTIONAL RELATIONSHIP BETWEEN THE VARIOUS FACTORS OF SYSTEM DYNAMICS MODEL OF HATCs

(1) F22 = 100 Units: square/ person
(2) F12 = 0.833* F11+ 0.167* F10+ initial value
(3) F24 = DELAY1I (MF3* F29, delay time, 0)
(4) F23 = 0.5538* F6+ 0.1259* F16+ 0.0727* F4+ 0.2477* F1
(5) F19 = 0.875* MF2+ 0.125* F16+ initial value
(6) MF1 = INTEG (F23- F24, initial value)
(7) F6 = 0.5936*(F8/F21)* F22+ 0.2493* F1 +0.1571* F3+ initial value
(8) F18 = 0.3333* MF2+ 0.6667* F16+ initial value
(9) F7 = assignment according to the questionnaire data
(10) F21 = 3000 square, which was assigned by estimating
(11) F15 = WITH LOOKUP (MF2, (MF2, F15))
(12) F20 = assignment according to the questionnaire data
(13) F2 = assignment according to the questionnaire data
(14) F10 = WITH LOOKUP (MF1, (MF1, F10))
(15) F5 = 0.2583* F6+ 0.1047* F4+ 0.637* F1+ initial value
(16) F27 = 60 assigned according to the Fact Units: person/ minute
(17) F26 = F2* Time* 60 Units: person
(18) F25 = F27* Time* 60+ STEP (F7* Time* 60, Time) Units: person
(19) F9 = 0.6667* F10+ 0.3333*MF1+ initial value
(20) F8 = INTEG (F26-F25, 10000) 10000 referred to the initial value
(21) F4 = 0.5*F1+ 0.5*F6+ initial value
(22) F13 = 0.1047* MF1+ 0.2583* F14+ 0.637* F14+ initial value
(23) F14 = WITH LOOKUP (MF1, (MF1, F14))
(24) F1 = assignment according to the questionnaire data
(25) F3 = 1 1 referred to HATC appeared at a special time node.
(26) MF2 = INTEG (MF2+ F28, initial value)
(27) F28 = 0.3005* F12+ 0.0448*F10+ 0.3272* F11+ 0.0845*F13+ 0.1327* F14+ initial value
(28) F29 =5 assigned by this paper
(29) F17 = 0.25* MF2+ 0.75* F16+ initial value
(30) MF3 = INTEG (F30+ MF3, initial value)
(31) F30 = DELAY1I ((0.1193* F19+ 0.3204* F18+ 0.0614* F15+ 0.2943* F17+ 0.1063* F16+ 0.0983* F20), delay time, 0)
(32) F16 = 0.25* MF2+ 0.75* F15
(33) F32 = 1/3 *(MF1+ MF2+ MF3)
(34) F31 = (MF1* MF2* MF3) / (MF1+MF2+MF3) ^^{2}*1/ (2*MF3+ MF1) ^^{2}*1/ (2*MF3+MF2) ^^{2}
(35) F33 = 3* F31 (C) ^$^{1/3}$
(36) The safety of system = (F32* F33) ^$^{1/2}$

To be noticed, this paper assigned F22 as 100. The reason was that there was a huge pressure among the crowd affecting the safety. In addition, this paper assigned F29 as 5 because MF3 enlarged the management effect. Obviously, it spent some time before achieving the effect of MF3. Therefore, this paper used delay function, DELAY, to explain F24. Similarly, F30 also used delay function, DELAY. The reason is when organizer took measure to make response to state mutation, which spent a period of time. When the f8 reached a certain level, the early warning would be excluded. F7 was used step function, STEP. In addition, F14 and F10 were affected by MF1. However, MF2 affected F15. Then this paper used scatter diagrams to reveal the relationship between them, which were shown in following Figure. According to the scatter diagrams, the linear relationship between variables was not obvious. Therefore, this paper used a special function, WITH LOOKUP to explain the relationship of these variables.

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