Appl. Math. Inf. Sci. 6 No. 1S pp. 9S-14S (2012)

Applied Mathematics & Information Sciences
An International Journal

Research on Risk Assessment System of Mass Crowded Stampede-trampling Accidents in Stadium

Li Menglong[1], Peng Hongjian[2*1], Zhang Xinkang[1], and Deng Luoping[1]
[1] Physical Education Institute, Hunan University of Science and Technology, Hunan, China
[2] School of Chemistry and Chemical Engineering, Central South University, Hunan, China
Email Address: sbssqdx@yahoo.com.cn

Received: Received May 02, 2011; Revised July 25, 2011; Accepted September 12, 2011
Published online: 1 January 2012

Abstract: Objective: Researching the main factors causing mass crowded stampede-trampling accidents in stadium and establishing a risk assessment system of mass crowded stampede-trampling accident in stadium. Method: Analyzing and studying the risk of mass crowded stampede-trampling accident in stadium in the way of logic inference, Delphi method, AHP, comprehensive analysis and demonstration analysis. Conclusions: The risk assessment indicator system of mass crowded stampede-trampling accident in stadium established with four first-level indicators and twenty-nine second-level indicators are highly scientific and effective. it's feasible to assess the risk of mass crowded stampede-trampling accident in stadium by using fuzzy comprehensive assessment method.

Keywords: Assessment, Mass Crowded Stampede-trampling Accidents; Stadium

1 Introduction

With the improvement of people's material and cultural [l] conditions, the construction and promotion of urban public venues become faster and faster. There are many potential dangers and risks existing in pubic places with highly crowded massive people and long evacuation travel distance where mass crowded stampede-trampling accident of high casualty usually happens due to various uncertain & sudden causes1. In recent years, with the improvement of people's life, there are more and more people like to watch sports event and watching sports events has become an important part of people's spare-time cultural life. However, the occurrence of accident and disaster in the stadium is becoming higher and higher. According to the accident data statistics of Dickie and Fruin [2,3] there were about more than 3000 casualties in the recent ten years around the world, and the accidents happened in stadium always cause mass casualties. The probability of injury or death in such accidents is bigger than that of frequent accidents (car crash).

Mass crowded stampede-trampling accident always happens suddenly and causes great society influence. The scholars like Lee [4] and Helbing [5] made quantitative analysis on mass crowded stampede-trampling accident from its definition and made intensive research on the main causes of such accidents which provided theory basis for mitigating or solving the mass crowded stampede-trampling accident. In addition, Henein [6] and other scholars also made relevant research on the causes and solutions of mass crowded stampede-trampling accidents. Teknomo [7] described the acting forces

[1] **Corresponding Author: Peng Hongjian, phj108@163.com**

among individuals of main causing crowd in details in the method of microcosmic modeling, providing important theory basis for this study subject. Foreign researches on this subject mainly reflect in crowd dynamics, which is analyzing the crowd behaviors in normal situation or emergency by constructing relevant macrocosmic or microcosmic modeling. Comparing with foreign research, domestic research in this field mainly concentrates on social management, such as the research of Zhiying Hu [8] and Liping Kouu [9] Moreover, some researches analyze the causes of mass crowded stampede-trampling accident [10, 11] and provide solutions for such accidents. There are some scholars [12, 13] trying to study the quantitative approach of stranded crowd and safe evacuation, and put forward the general analysis method for crowded stampede-trampling accidents. However, there is no domestic research about the risk assessment system of mass crowded stampede-trampling accidents in stadium. It restricts the precaution and solution of mass crowded stampede-trampling accidents in stadium to some extent. Therefore, the establishment of a scientific, objective, rational and highly operational risk assessment system of mass crowded stampede-trampling accidents in stadium can enrich and develop the theory structure of research on mass crowded stampede-trampling accidents in stadium and has significant practical influence on preventing such accidents.

Time	Spot	Accident cause	Number of injury	Number of deaths
1964	Lima	Stampede-trampling	500	318
1968	Buenos Aires	Stampede-trampling	204	74
1971	Ibrox	Stampede-trampling	140	66
1982	Lenin，Moscow	Pushing and squeezing in a panic		340
1985	Bradford	Fire hazard	100+	56
1989	Hillsborough，Sheffield	Pushing and squeezing	400+	95
1996	Guatemala City	Panic	180	83
2001	Accra	Pushing and squeezing in a panic	277	126

Table.1 Disaster statistics of serious sporting area accidents around the world

2 Procedure and Method

2.1 Logic Inference

On the basis of reading literature, individual interview and using experience, this research started from the key elements that can reflect the mass crowded stampede-trampling accidents in stadium and made experience selection to the assessment indicators of mass crowded stampede-trampling accidents in stadium following the procedure of "theory-concept-operationalization-indicator", and primarily formed a risk assessment system of mass crowded stampede-trampling accidents in stadium including four first-level indicators and thirty-seven second-level indicators(specific indicators are omitted).

2.2 Delphi Method- Screening Indicators

In one research of social indicators, the way of first choosing a qualified expert panel and then making indicator selection through Delphi method is always considered as a scientific, comparative objective and strong operational method. [14] In order to establish the risk assessment indicator system of mass crowded stampede-trampling accidents in stadium, in this study we invited [15] experts in the fields of social sports, sports management, construction planning and sports event responsible person respectively to form a expert panel, and made questionnaire to them three times. At last, we combined some indicators according to the suggestion of experts and defined a risk assessment system of mass crowded stampede-trampling accidents in stadium including four first-level indicators and twenty-nine second-level indicators.

2.3 Analytic Hierarchy Process(AHP)- Calculate the Weight of Each Indicator [15]

2.4 Defining the Assessment Method-defining by Using Fuzzy Comprehensive Assessment Method

Because the indicators used to assess the risk of mass crowded stampede-trampling accident in stadium don't have definite concept extension, they are hard to be described in classical mathematical language or measured by fixed standards. It is a typical fuzzy issue. Therefore, the fuzzy comprehensive assessment method is effect when it is applied to assess the risk of RQ by fuzzy transformation according to given assessment standards and measured values.

3 Procedure and Method

3.1 The Assessment Indicator of Mass Crowded Stampede-trampling Accidents in Stadium

In this research, we divided the mass crowded stampede-trampling accidents in stadium into four groups which were caused by management factor, environmental factor, personal factor and stadium factor, and set corresponding assessment indicators according to their contents. After comprehensively considering the current situation of mass crowded stampede-trampling accidents in stadium and seeking for suggestions from relevant experts in the fields of environment, safety and construction, we determined the indicator system of mass crowded stampede-trampling accidents in stadium. According to the evaluations of experts to the indicators, the weight of each indicator was determined by using AHP. Finally the assessment system of mass crowded stampede-trampling accidents in stadium was established by using fuzzy comprehensive assessment method to determine the assessment method of mass crowded stampede-trampling accidents in stadium (see Fig.1).

3.2 Defining the Weight of Each Indicator

This research adopted AHP to determine the weight of each indicator. The advantage of AHP is combing qualitative determination with quantitative determination and thus has high logicality, systematicalness, conciseness and practicability. AHP can solve the multilevel and multiple-objective programming and planning issues more scientifically and rationally. The procedure of calculating the weight of each risk assessment indicator of mass crowded stampede-trampling accidents in stadium by using AHP is presented as follows:

Step one: Establishing the progressive level structure of indicator system, which means establishing the recursion-order level of indicators according to the fundamental relation of assessment indicator system. In the indicator system, the factor in each level governs the corresponding factor in the lower level, in which way the progressive pyramid-type level structure constituted by one general objective level and some sub-objective level is formed.

A	A_1	A_2	A_3	A_4	M_i	W_i
A_1	1	2	1/4	1/3	0.1667	0.14
A_2	1/2	1	1/3	1/2	0.0833	0.11
A_3	4	3	1	2	24	0.47
A_4	3	2	1/2	1	3	0.28

Table.2 Assessment matrix of some expert under level A

Step two: Establishing a pairwise assessment matrix. Considering the article length, we only establish one expert judgment matrix of A_1, A_2, A_3 and A_4 vs A (see table 2). The detailed steps are as follows:

 Calculating the assessment matrix

M_1=1×2×1/4×1/3=0.1667 M_2=1/2×1×1/3×1/2=0.0833

M_3=4×3×1×2=24 M_4=3×2×1/2×1=3

Calculating the nth roots of M_i, $\overline{W_i}$

From the formula of $\overline{W_i} = \sqrt[n]{M_i}$, we can get the result: $\overline{W_1}$ =0.6389, $\overline{W_2}$ =0.5373, $\overline{W_3}$ =2.2134, $\overline{W_4}$ =1.3161

Making uniformization of vector

$\overline{W}$=[$\overline{W_1}$, $\overline{W_2}$, $\overline{W_3}$, $\overline{W_4}$]

W_1=0.6389/0.6389+0.5373+2.2134+1.3161=0.14

W_2=0.5373/0.6389+0.5373+2.2134+1.3161=0.11

W_3=2.2134/0.6389+0.5373+2.2134+1.3161=0.47

W_4=1.3161/0.6389+0.5373+2.2134+1.3161=0.28

Then getting the desired eigenvector W=[0.14, 0.11, 0.47, 0.28]

Calculating the maximum characteristic root of judgment matrix $\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i}$

From it getting $(AW)_1$=0.5750, $(AW)_2$=0.4787, $(AW)_3$=1.9154, $(AW)_4$=1.1506

Formula: $\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} = \frac{(AW)_1}{4W_1} + \frac{(AW)_2}{4W_2} + \frac{(AW)_3}{4W_3} + \frac{(AW)_4}{4W_4}$ =4.1532

Consistency check: CI=$\frac{\lambda_{max} - n}{n-1}$=0.0511

CR=CI/RI=0.0511/0.90=0.0568 < 0.10 (Ri is the mean random consistency indicator whose value is presented in table 3)

	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.52	0.90	1.12	1.24	1.32	1.41	1.45

Table.3 Mean Random Consistency Indicator Table

Step three: Testing the order consistency of other levels. Except the judgment matrix of the third expert, the judgment matrixes of other experts all passed the consistency test.

Step four: Comprehensive settlement. We calculated the overall weight of each indicator which is presented in Fig.1.

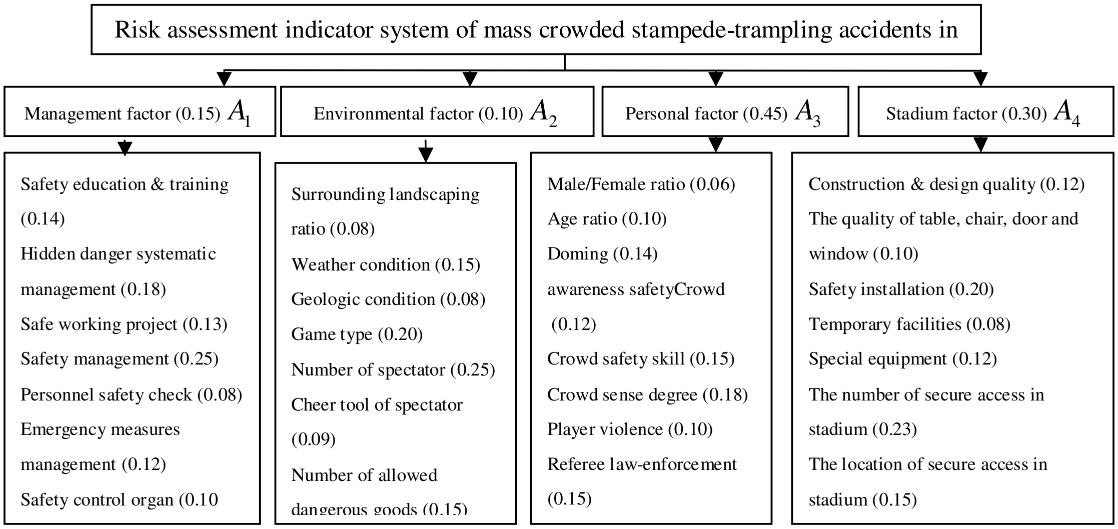

Fig.1 Risk assessment indicator of mass crowded stampede-trampling accidents in stadium and indicator weight

4. Assessment Method

The mathematical model of fuzzy comprehensive assessment can be divided into first-level model and multilevel model. According to the analysis of assessment factors, some factors have coordinative relation, and some factors have causal relation, which means the factors are in different levels and it is an existed practical problem. This research adopted multilevel fuzzy comprehensive assessment model to make analysis. Fig.2 presents the modeling steps of multilevel model.

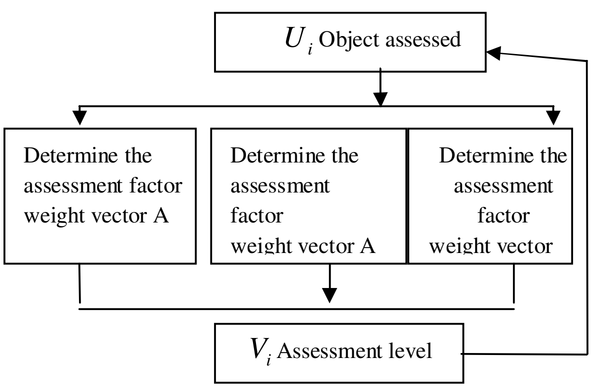

Fig.2 Modeling steps of multilevel fuzzy comprehensive assessment

Multilevel fuzzy comprehensive assessment model: First making comprehensive assessment to the factors of lower levels, and then making comprehensive assessment of high levels to the assessment results. The detailed procedure is as follows:

(1) Defining the factor collection of object assessed F= { f_1, f_2, …, f_n } .According to the assessment indicators of mass crowded stampede-trampling accidents in stadium, the first-level assessment factors determined are f_1 (management factor), f_2 (Environmental factor), f_3 (personal factor) and f_4 (stadium factor). The second-level assessment factors are the sub-factors of every indictor in Fig.1.

(2) Determining the assessment collection E = { e_1, e_2, …, e_n } . The assessment levels of mass crowded stampede-trampling accidents in stadium are defined into five levels E ={very high, high, general, low, very low}, and the corresponding values are 90, 80, 70, 60 and 50.

(3) Defining the weight collection W_f . The weight of assessment factors in every level can be defined in the method described in 2.2.

(4) Making signal factor assessment. Establishing f, a fuzzy mapping from factor collection F to assessment collection E, and then deriving a fuzzy relation R_f from f, whose matrix representation is $R_i = R_f = (\gamma_{ikj}\ m\times n)$, where γ_{ikj} represents the subjection of factor f_{ik} to assessment e_j. Generally, R_i is called signal factor matrix, and defining the value of signal factor assessment

matrix R_i is the point of the assessment work which is usually made by sampling survey method.

(5) Comprehensive assessment. As to the given weight A, the fuzzy comprehensive assessment is a fuzzy mapping from factor collection F to assessment collection E: $T_f A \to B = T_f(A) = W_{fo} R$, where o represents the fuzzy operator adopted in weight vector and signal factor fuzzy assessment matrix. According to the following formula, we can calculate and obtain the comprehensive assessment vector S and comprehensive assessment value μ. $S = W_f R$, $\mu = W_e' S^T$

In a word, the multilevel fuzzy comprehensive assessment model can reflect the level property of factors of object assessed and avoid the difficulty of weight distribution caused by the large amount of factors. It is more elaborate than signal level model and can reflect the interrelation of factors more correctly.

A	B_1	B_2	B_3	B_4	W_i	W_{io}	λ_{mi}
B_1	1	1	2	3	1.565	0.351	4.009
B_2	1	1	2	3	1.561	0.351	4.009
B_3	1/2	1/2	1	2	0.841	0.189	4.011
B_4	1/3	1/3	1/2	1	0.486	0.109	4.014

Table.4 Assessment matrix and process of weight calculation and consistency test

5 Conclusion

We established a risk assessment system of mass crowded stampede-trampling accidents in stadium including four first-level factors which are management factor, environmental factor, personal factor and stadium factor, and twenty-nine second-level factors by using empirical selection, Delphi method, AHP and fuzzy comprehensive assessment, and defined the weight and assessment method of indicators. This system makes it possible to make quantitative evaluation to mass crowded stampede-trampling accidents in stadium.

The research on risk assessment system of mass crowded stampede-trampling accidents in stadium has theoretical value and provides theory support to the risk assessment of such accidents. More important, it has practical value and strong operability which can be applied to the assessment of mass crowded stampede-trampling accidents in stadium directly. In the practical generalization of this system, we should consider the practical situation of sports event to modify and adjust this risk assessment system on the basis of current & local conditions instead of copying the theory to practice blindly.

Acknowledgements

This work is supported form A Project Supported by Hunan Provincial Sports Bureau (Kt11-006) provided by Li Menglong and A Project Supported by Scientific Research Fund of Hunan Provincial Education Department (08c307) provided by Zhang Xinkang.

References

[1] ZHANG Qingsong and LIU Mao, A stranded-crowd model (SCM) for performance-based design of stadium egress, *Building and Environment*. 7 (2007), 2630.

[2] Kristin Hoskin, Fire Protection and Evacuation Procedures of Stadia Venues in New Zealand, *University of Canterbury*. 2004.

[3] www.crowddynamics.com/Main/Crowdaccidents.htm.

[4] Ris S. C. Lee and Roger L. Hughes, Exploring trampling and crushing in a crowd, *Journal of Transportation Engineering*. 131 (2005), 575.

[5] D.HELBING, Traffic and related self-driven many-particle systems, *Reviews of Modern Physics*. 4 (2001), 1067.

[6] Henein, Colin M. White, Tony, Macroscopic effects of microscopic forces between agents in crowd models, *Statistical Mechanics and Its Applications*. 373 (2006), 694.

[7] Teknomo and Kardi, *Development of An Image Processing Data Collection and Simulation Model*, 2002.

[8] HU Zhiying and YE Minghai, Research on Precaution System of Crowd Pushing and Squeezing Accidents in Large-scale Social Activities, *Disaster Science*. 1 (2006), 108.

[9] KOU Liping, Cause Analysis and Precaution Research of Crowded Stampede-trampling Accident, *Journal of Chinese People's Public Security University*. 4 (2005) 16.

[10] REN Changxing, WU Zongzhi and LIU Mao, Analysis of Crowd Stampede-trampling Accident in Urban Public Place, *China Safety Science Journal*. 12 (2005), 103.

[11] LI Jianfeng, LIU Mao and SUI Xiaolin, The Comprehensive Measurement of the Influence of Accident Type Factor on People Gathering Risk, *Journal of Safety and Environment*. 5 (2007) 119.

[12] ZHANG Qingsong, LIU Mao and ZHAO Guomin, Quantitative Model Research on Stranded People During Evacuation in the Sports Field, *Journal of Safety and Environment*. 3 (2006), 21.

[13] HANG Qingsong, LIU Mao and ZHAO Guomin, A

modify of evacuation time computational model forstadium crowd risk analysis, *Process Safety and Environmental Protection*. B4, 1, 2002.

[14] ZHOU Dengsong, YU Daoming, Research on Modern Indicator System of Capital Sports, *Journal of Beijing Sports University*. 5 (2007), 581.

[15] LIU Wei, Research on the Influencing Factors of AHP to Physical Education Teaching Presentation Training Method of Special School, *Journal of Hunan University of Science and Technology*. 3, 125 (2007).

Li Menglong received the Bachelor's degree in education from Wuhan Institute of Physical Education in 2001, and the Master's degree in education from the Beijing Sports University in 2007. He is currently an lecturer in the Hunan University of Science and Technology. His research interests are in the areas of physical education, physical exercise, and exercise psychology.

Peng Hongjian received the Master's degree in education from Hunan Normal University in 1998, and the Ph.D in education from the Central South University in 2007. He is currently an vice professor in the Central South University. His research interests are in the areas of education and new energy materials.

Zhang Xinkang received the Bachelor's degree in education from Hunan City Institute in 1992, and the Master's degree in education from the Hunan University of Science and Technology in 2009. He is currently an researcher in the Hunan University of Science and Technology. His research interests are in the areas of higher education.

Deng Luoping received the Bachelor's degree in education from Wuhan Institute of Physical Education in 2001, and the Master's degree in education from the Beijing Sports University in 2008. He is currently an lecturer in the Hunan University of Science and Technology. His research interests are in the areas of physical education and physical exercise.