Analysis and study on the stadium personnel evacuating strategy using performance-based model

Zhao Hong[1]*

[1] *Jilin Normal University, SiPingCity, JiLin Province, China, 136000*

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Abstract

To protect the personal safety of people during entertainment in the technologically advanced society, this study investigated the safe personnel evacuation strategy in case of emergencies in stadium, in an attempt of minimizing the personnel losses. Considering the influences of personnel panic, evacuation exit flow, perception time, and the evacuation experience of staffs, the proportions of factors influencing the emergent stadium personnel evacuation efficiency were obtained using analytic hierarchy model, i.e., disorder evacuation, short evacuation time, and slow evacuation accounted for 0.386, 0.272, and 0.342 respectively. This result suggested that disorder evacuation and slow evacuation were the main factors for inducing the low efficiency of stadium personnel evacuation, while short evacuation time took a low proportion. Therefore, it was proved that the evacuation routes in most of the buildings were reasonably designed; the disorder evacuation caused by personnel panic acted as the main factor inducing the low personnel excavation efficiency; the personnel evacuation experience deficiency of most of the staffs resulted in the slow evacuation speed. Therefore, to prevent large accidents, the masses should strengthen the learning for scientifically coping with accidents. Meanwhile, the stadium managers should conduct professional quality training to the staffs at regular time

Keywords: SOFC; performance-based model; evacuation strategy; analytical hierarchy process

1 Introduction

Since the reform and opening up, China's economy is in booming development, which drives the rapid increase of China's strength in various aspects. In the following 36 years, China's industry, agriculture, information industry, business, and education etc. saw rapid development. For all industries, building is the indispensable demand. Therefore, with growing of people's living demands in China, city becomes more and more modern with increasingly high the building and increasingly large shopping malls and public places. But on the other hand, due to many reasons, such as unreasonable building construction design, the difference of actual situation and the theoretical condition, and uncertainty of human factors, some major accidents (such as fire and trampling) happened in many occasions in the past, resulting in great casualties and financial losses. In consequence, China publishes and implements a lot of prevention and emergency measures. Unfortunately, such accident is still not avoided. The main reason lays in the uncontrollability of human factors, that is, the deficient safety awareness, the excitement and panic in case of accidents, and the evacuation experience deficiency of staffs. Therefore, even in condition of reasonable building structure design, accidents also happen. To more effectively prevent the accidents in each industry and evacuate the crowd in case of accidents, this study exampled the stadium to analyze and study the personnel evacuation strategy.

2 Establishment of the Model

According to China's building code for fire protection, China's building performance-based fire safety goal is to protect personnel safety, property safety, the continuous operation of facilities, and environment etc... The personnel safety therein takes the highest proportion. Therefore, this study set the personnel safety protection as the main goal to analyze the stadium personnel evacuation.

2.1 ESTABLISHMENT OF HIERARCHICAL STRUCTURE

To find the reason inducing the low evacuation efficiency, it is firstly needed to determine the most influencing unit on personnel excavation, that is, the main influencing factor for the personnel evacuation in stadium. Subsequently, the low personnel evacuation efficiency in stadium is quantified basing on hierarchy analysis. Finally, the relationship of target layer, criterion layer, and plan layer is built.

Target layer: low stadium personnel evacuation efficiency.

Criterion layer: the influencing factors of the plan, including personnel panic Y_1, evacuation route flow Y_2, perception timeY_3, and the evacuation experience of staffs Y_4.

Plan layer: disorder evacuation V_1, short evacuation time V_2, and slow evacuation speed V_3. The hierarchical structure is obtained, as shown in Figure 1.

* *Corresponding author's* e-mail: zhaohongswsw@163.com

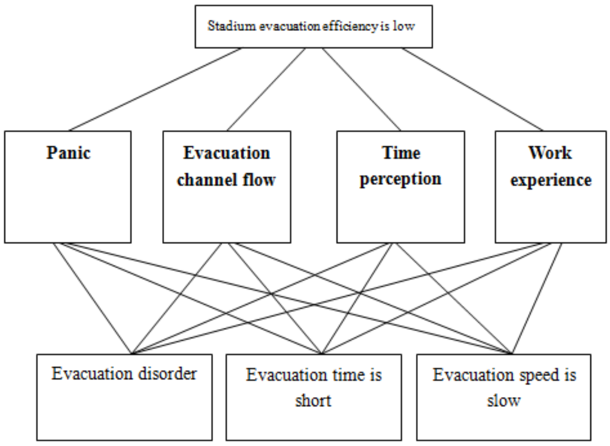

FIGURE 1. Hierarchical structure

2.2 CONSTRUCTION OF JUDGMENT MATRIX

To obtain the comparative quantitative judgment matrix of factors, scale of 1~9 was set, as shown in Table 1.

TABLE 1. Scale 1~9

Scale a_{ij}	Definition
1	Factor *i* is equally important with factor *j*.
3	Factor *i* is more important than factor *j* slightly.
5	Factor *i* is more important than factor *j*.
7	Factor *i* is more important than factor *j* greatly.
9	Factor *i* is more important than factor *j* absolutely.
2, 4, 6, 8	The scales for judging the intermediate state of the judgments above.
Reciprocal	If comparing factor *i* with factor *j*, judgment value a_{ji} =1/ a_{ij} and a_{ii} =1 are obtained.

α_{ij} is set as the ratio for influences of β_i and β_j on *G*. Thus the judgment matrix *A* is obtained. A_1 represents the judgment matrix between the second hierarchy with the first hierarchy, with element of α_{ij}, divisor of α_i, α_j, and factor A_1. Thus the judgment matrix A_1 is expressed as:

$$A_1 = \begin{bmatrix} A_1 & \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 \\ \alpha_1 & a_{11} & a_{12} & a_{13} & a_{14} \\ \alpha_2 & a_{21} & a_{22} & a_{23} & a_{24} \\ \alpha_3 & a_{31} & a_{32} & a_{33} & a_{34} \\ \alpha_4 & a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \quad (1)$$

The α_{ij} in the equation above is generally valued by the proportional scale1～9, as shown in Figure 2.

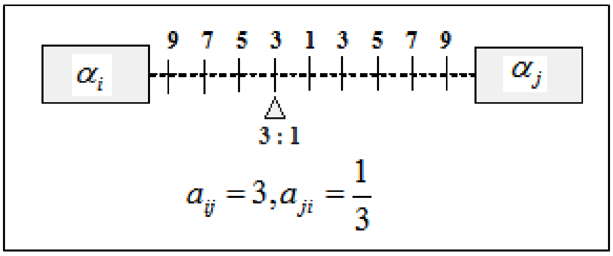

FIGURE 2. The valuing by the scale1～9

According to the experience of a number of experts, the research results in references, as well as the scale setting of 1~9, the pairwise comparison matrix is obtained, namely, Tables 2-6 is the judgment matrix.

TABLE 2. Comparison matrix

G	Y_1	Y_2	Y_3	Y_4
Y_1	1	5	5	6
Y_2	1/5	1	3	3
Y_3	1/5	1/3	1	1
Y_4	1/6	1/3	1	1

TABLE 3. Comparison matrix

Y_1	V_1	V_2	V_3
V_1	1	6	6
V_2	1/6	1	1
V_3	1/6	1	1

TABLE 4. Comparison matrix

Y_2	V_1	V_2	V_3
V_1	1	1/4	1/3
V_2	4	1	1/2
V_3	3	2	1

TABLE 5. Comparison matrix

Y_3	V_1	V_2	V_3
V_1	1	1/4	1/3
V_2	4	1	1
V_3	3	1	1

TABLE 6. Comparison matrix

Y_4	V_1	V_2	V_3
V_1	1	1/3	1/5
V_2	3	1	1/2
V_3	5	2	1

2.3 CONSISTENCY CHECK

The index test formula of consistency is expressed as $CI = \frac{\lambda_{\max} - n}{n-1}$, where, $\lambda_{\max}$ is the maximum eigenvalue of the comparative matrix; *n* is the order of the comparative matrix. It can be seen that judgment matrix is inversely proportional to *CI*.

$$C = \begin{Bmatrix} 1 & 5 & 5 & 6 \\ 1/5 & 1 & 3 & 3 \\ 1/5 & 1/3 & 1 & 1 \\ 1/6 & 1/3 & 1 & 1 \end{Bmatrix}$$

$$\xrightarrow{Column\ vector\ normalization} \begin{Bmatrix} 0.638 & 0.750 & 0.5 & 0.545 \\ 0.128 & 0.150 & 0.3 & 0.273 \\ 0.128 & 0.050 & 0.1 & 0.091 \\ 0.107 & 0.050 & 0.1 & 0.091 \end{Bmatrix}$$

$$\xrightarrow{According\ to\ the\ row\ sum} \begin{Bmatrix} 2.433 \\ 0.851 \\ 0.369 \\ 0.348 \end{Bmatrix}$$

$$\xrightarrow{The\ normalized} \begin{Bmatrix} 0.608 \\ 0.213 \\ 0.092 \\ 0.087 \end{Bmatrix} = \mathrm{W}^{(0)}$$

$$CW^{(0)} = \begin{Bmatrix} 1 & 5 & 5 & 6 \\ 1/5 & 1 & 3 & 3 \\ 1/5 & 1/3 & 1 & 1 \\ 1/6 & 1/3 & 1 & 1 \end{Bmatrix} \begin{Bmatrix} 0.608 \\ 0.213 \\ 0.092 \\ 0.087 \end{Bmatrix} = \begin{Bmatrix} 6.107 \\ 2.135 \\ 0.985 \\ 0.887 \end{Bmatrix}$$

$$\lambda_{\max}^{(0)} = \frac{1}{4}\left(\frac{6.107}{0.608} + \frac{2.135}{0.213} + \frac{0.985}{0.092} + \frac{0.887}{0.087}\right) = 4.17$$

$$w^{(0)} = \begin{pmatrix} 0.608 \\ 0.213 \\ 0.092 \\ 0.087 \end{pmatrix}$$

Judgment matrix is:

$$C_1 = \begin{Bmatrix} 1 & 6 & 6 \\ 1/6 & 1 & 1 \\ 1/6 & 1 & 1 \end{Bmatrix}, C_2 = \begin{Bmatrix} 1 & 1/4 & 1/3 \\ 4 & 1 & 1/2 \\ 3 & 2 & 1 \end{Bmatrix},$$

$$C_3 = \begin{Bmatrix} 1 & 1/4 & 1/3 \\ 4 & 1 & 1 \\ 3 & 1 & 1 \end{Bmatrix}, C_4 = \begin{Bmatrix} 1 & 1/3 & 1/5 \\ 3 & 1 & 1/2 \\ 5 & 2 & 1 \end{Bmatrix}$$

The corresponding maximum eigenvalue and eigenvector are

$$\lambda^{(1)}{}_{\max} = 3.36, w^{(1)}{}_1 = \begin{Bmatrix} 0.366 \\ 0.366 \\ 0.465 \end{Bmatrix}$$

$$\lambda^{(2)}{}_{\max} = 4.43, w^{(1)}{}_2 = \begin{Bmatrix} 0.532 \\ 0.264 \\ 0.081 \end{Bmatrix}$$

$$\lambda^{(3)}{}_{\max} = 3.34, w^{(1)}{}_3 = \begin{Bmatrix} 0.645 \\ 0.243 \\ 0.133 \end{Bmatrix}$$

$$\lambda^{(4)}{}_{\max} = 3.25, w^{(1)}{}_4 = \begin{Bmatrix} 0.625 \\ 0.232 \\ 0.193 \end{Bmatrix}$$

According to $CI = \frac{\lambda_{\max} - n}{n-1}$, *RI* is obtained, as shown by Table 7.

TABLE 7. The RI value

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

As for judgment matrix *C*, $\lambda^{(0)}{}_{\max} = 4.43, RI = 0.99$

$$RI = \frac{4.43-4}{4-1} = 0.086 \quad (2)$$

$$CR = \frac{CI}{RI} = \frac{0.083}{0.99} = 0.087 < 0.1 \quad (3)$$

This result suggests that the inconsistency degree of *C* is in the allowable range. Thus the eigenvector of *C* can replace weight vector. Similarly, the consistency of the judgment matrix C_1, C_2, C_3, and C_4 are checked and passed the test. The calculation results from the target layer to the plan layer are got, as shown in Figure 3.

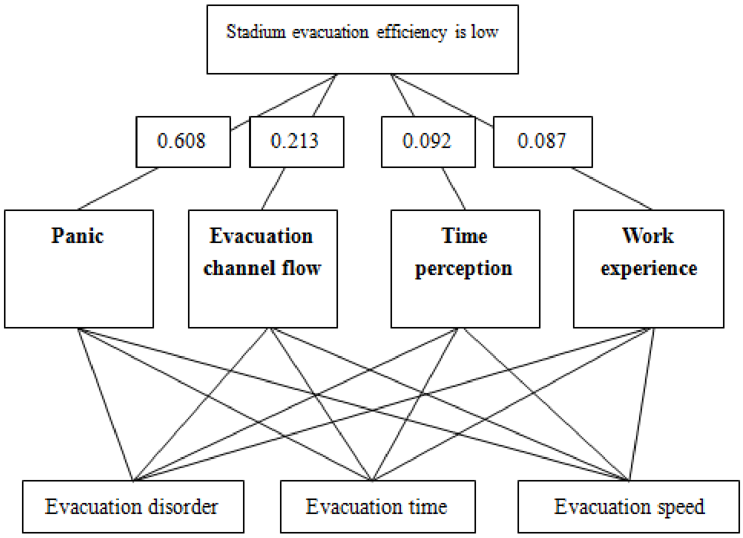

FIGURE 3. The calculation results from the target layer to the plan layer

$$\left\{\begin{matrix}0.366\\0.366\\0.465\end{matrix}\right\},\left\{\begin{matrix}0.532\\0.264\\0.081\end{matrix}\right\},\left\{\begin{matrix}0.645\\0.243\\0.133\end{matrix}\right\},\left\{\begin{matrix}0.625\\0.232\\0.193\end{matrix}\right\}$$

The calculation structure is displayed as follows:

$$w^{(1)}=(w_1^{(1)},w_2^{(1)},w_3^{(1)},w_3^{(1)})$$
$$=\left\{\begin{matrix}0.366 & 0.532 & 0.645 & 0.625\\0.366 & 0.264 & 0.243 & 0.232\\0.465 & 0.081 & 0.133 & 0.193\end{matrix}\right\}$$

$$w=w^{(1)}w^{(0)}$$
$$=\left\{\begin{matrix}0.366 & 0.532 & 0.645 & 0.625\\0.366 & 0.264 & 0.243 & 0.232\\0.465 & 0.081 & 0.133 & 0.193\end{matrix}\right\}\left\{\begin{matrix}0.608\\0.213\\0.092\\0.087\end{matrix}\right\}$$
$$=\left\{\begin{matrix}0.386\\0.272\\0.342\end{matrix}\right\}$$

According to the hierarchy analysis above, in the case of considering personnel panic, the evacuation route flow, perception time, and the evacuation experience of staffs etc., the proportions of the factors influencing the stadium personnel emergency evacuation efficiency were got, i.e., disorder evacuation, short evacuation time, and slow evacuation speed accounted for 0.386, 0.272, and 0.342 respectively. This result suggested that disorder evacuation and slow evacuation was the main factor causing the low efficiency of stadium personnel evacuation, while short evacuation time took a low proportion. Therefore, it was proved that the evacuation routes in most of the buildings were reasonably designed; the disorder evacuation caused by personnel panic acted as the main factor inducing the low personnel excavation efficiency; the personnel evacuation experience deficiency of most of the staffs resulted in the slow evacuation speed. Therefore, to prevent large accidents, the masses should strengthen the learning for scientific coping with accidents. Meanwhile, the stadium managers should conduct professional quality training to the staffs at regular time.

7 Conclusion

This paper firstly analyzed the causes for the casualties induced by the major safety accidents in China's large stadium. According to China's building fire code, it was learn about that China's building performance-based fire safety goal was to protect personnel safety, property safety, the continuous operation of facilities, and environment etc... The personnel safety therein took the highest weight.

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References

[1] Shi Jianyong, Shi Wenzhong, Ren Aizhu 2011 An integrated model for the fire safety analysis of large space buildings *Advances in Structural Engineering* **14**(5), 763-775

[2] Moriyama Shuji, Hasemi Yuji, Ogawa Junko, Sano Tomonori, Jin Tadahisa, Hebiishi Takahiro 2009 On-site experiment on the group evacuation behavior in large-scale underground shopping mall - Preference of pathway in passage crossing and cognition of exits *Journal of Environmental Engineering* **74**(637), 233-240

[3] *Deleted by CMNT Editor*

[4] Benichou Noureddine, Kashef Ahmed H., Reid Irene, Hadjisophocleous George V., Torvi, David A., Morinville Gaetan 2005 FIERAsystem: A fire risk assessment tool to evaluate fire safety in industrial buildings and large spaces *Journal of Fire Protection Engineering* **15**(3),145-172

[5] *Deleted by CMNT Editor*

[6] WANG Wei-hua, WU Shu-xian, CHENG Jian 2010 Mathematical Model of Evacuation Program in a Building *Journal Of Wuhan University Of Technology* **32**(11), 155-158, 162

[7] *Deleted by CMNT Editor*

[8] Yao Jian 2010 Research on eevaluation indicator system for construction of demonstrative building based on Analytic Hierarchy Process theory *ICIMA- Int. Conf. Ind. Mechatronics Autom* **2**, 418-421

Author

ZHAO Hong, 1970.02, Wuwei City, Gansu Province, P.R. China

Current position, grades: the Research Assistant of Jilin Normal University in Jilin Province, China.
University studies: received her B.Sc in Teaching Management from Jilin Provincial Institute of Education in China.
Scientific interest: Her research interest fields include Stadium and Gymnasium.
Publications: more than 6 papers published in various journals.
Experience: She has teaching experience of 26 years, has completed five scientific research projects.