International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 3 Issue 8 ǁ August. 2015 ǁ PP.40-48

Study On Monorail Sky Train Passenger Landing Facilities

Wang Xin, Fang Yu, Zhang Guo-fu

(College of Urban Railway Transportation, Shanghai University of Engineering Science, Shanghai 201620, China)

ABSTRACT*: In order to effectively solve the problem of hanging monorail sky train evacuation of passengers, three kinds of passengers evacuation equipments are deeply studied. They are independent staircases, high-altitude operation truck, flexible slip pocket. The structure of these equipments are respectively introduced. And these economy, timeliness and practical performance are analysed. Then, a comprehensive evaluation model of hanging monorail sky train evacuation facilities is established based on analytic hierarchy process (AHP). The composite score for every kind of passengers evacuation equipments is calculated. The results show that every kind of passenger evacuation facilities in this paper has some defects. It is needed to develop a kind of economic, efficient and practical hanging monorail sky train passenger evacuation equipment, so as to provide technical support for the application of this type of vehicle.*

Keywords*: monorail sky train; passenger evacuation; analytic hierarchy process; comprehensive evaluation*

I. INTRODUCTION

In the 1980s, a kind of hanging monorail sky train system with friendly environmental began to be developed in Germany. This public transportation system had small impact on the original building and environment, and it can get alone with existing public transportation system. After years of development, more and more sky train lines came into use in Germany, Japan and other countries. In 2011, the Air Train International introduced the technology of H - Bahn into China，and then in 2014, a shrunken model of sky train vehicle appear in the 16th China International Industry Fair.

Compared with the traditional urban rail transit system, the sky train system has certain advantages. For example, it cost less time and it needs less land. Because of its carbody under the rail, people in this kind of public transportation system is hard to evacuate in case of emergency. In the reference [1], the author puts forward that the trouble of hanging monorail sky train unable to be quickly handled in emergency.

In this paper, three kinds of passengers evacuation equipments will be compared. Hope to provide certain technical support for the application of this type of vehicle in china.

II. Sky Train Passenger Landing Facilities

Currently, the solution of hanging monorail sky train evacuation of passengers can be divided into waiting for save left in faulted vehicle and falling to the ground. These two solution complement each other. The solution waiting for save left in faulted vehicle rely on the specialized rescue vehicles, and if the rescue vehicles could't arrive for some reason, people should fall to the ground timely. There are three kinds of landing facilities to use. They are independent staircases, high-altitude operation truck and flexible slip pocket.

A The Independent Staircases

There have been a large amount of application about the independent staircases[2]. For example, the

independent staircases and flexible slip pocket of Chiba Urban Monorail in Japan have been shown in Figure 1. The independent staircases used in hanging monorail sky train have a evacuation platform near the floor of the vehicle, and between the platform and ground, there is stairs. The independent staircases is supported by an independent pillar.

B The High-altitude Operation Truck

The high-altitude operation truck like fire trucks, can rapidly reach the failed vehicle, then transfer passengers to the ground through its lift arm platform , as shown in figure 2.

Fig. 1 The independent staircases and flexible slip pocket of Chiba Urban Monorail in Japan

Fig. 2 The high-altitude operation truck

C The Flexible Slip Pocket

Japanese transplanted the flexible slip pocket used in high-rise to the hanging monorail sky train system after introducing this kind of public transit system, as shown in figure 1.To cope with this kind of rescue equipment, an exit need to open at the bottom of the vehicles. The upside of the flexible slip pocket should be fixed on the car body and the downside should be fall down from the exit when the flexible slip pocket is working. Under the pulling of rescue workers on the ground, the flexible slip pocket turn into two segments. One of them have a certain Angle with the floor of the vehicle and the another is parallel with ground.

III. Characteristics of the Sky Train Passenger Landing Facilities

According to the existing data, every hanging monorail sky train may be composed of three carriages, can

host 75 people per carriage, and the maximum height between car floor and ground is 8m.

A The Independent Staircases

The principle and structure of independent staircases which used for hanging monorail sky train is similar to which sued for The traditional track traffic system's widest bridge, so the economy of the independent staircases used for hanging monorail sky train can be estimated by the cost of independent staircases in traditional track traffic system's widest bridge. There are three independent staircases in the 2th widest bridge of Liao River in Beijing-Shanghai High-speed Railway, and the cost of them has been shown in table 1[3]. According to the date in table 1, the construction cost of an independent staircase with 1.5m width and 8m height is about 90 thousand RMB, and the maintenance charge is about 8 hundred RMB per year.

Table 1 the cost of independent staircases in the 2nd bridge of Liao River in Beijing-Shanghai High-speed Railway

	location	width、height	cost
1	DK544+580	1.5m、9.5m	One hundred and ten thousand RMB
2	DK547+580	1.5m、10m	one hundred and twenty thousand RMB
3	DK550+400	1.5m、12m	one hundred and fifty thousand RMB

The time that All passengers evacuated from the vehicle used can be calculated by the following formula[4]:

$$T = 1 + \frac{Q_1 + Q_2}{0.9\left[A_1\left(N-1\right) + A_2 B\right]} \tag{1}$$

Q_1 in the formula is the numbers of people in the vehicle, its value is 225 here; Q_2 is the numbers of people on the platform, its value is 0; A_1 is the transport capacity of the escalator, its value is 0 here; A_2 is the transport capacity of the stairs, its value is 70 according to the Code for the design of metro (GB 50157-2013)[5]; N is the numbers of escalator, its value is 0 here; B is the width of stair, its value is 1.5m here.

In conclusion, it would need 204 seconds that 225 people evacuate from the vehicle.

Independent staircases had a large number of applications in our traditional rail transit bridges and urban elevated bridge, its technological conditions have been relatively mature. However, in the hanging monorail sky-train system, the vehicle is at the bottom of the rail. After evacuating from the vehicle, passenger have no place to stand but to the platform and the independent staircases. So if passengers evacuate from the vehicle by the independent staircases , the faulted vehicle must have the continue driving ability to arrive at the independent staircases. This not only increased the dependence on outside conditions, but also reduces the timeliness. Its practical performance is not good.

B The High-altitude Operation Truck

GKS22 is a kind of typical crank-type high-altitude operation truck, the length of its platform is 1.8m, the width is 0.9m, and the height is 1.15m. GKS22s' maximum working height is 20.7m, Can satisfy the requirement of passenger evacuation in hanging monorail sky train system.

According to the dealers, every GKS22's price is about 8 hundred thousands RMB, annual maintenance cost is about 2 thousands RMB.

Assuming that the motion is uniform when the platform is rising and falling, and ignore the passenger waiting time. Then, the time that all passengers evacuated from the vehicle used can be calculated by the following formula:

$$T = \frac{Q}{q} \times \frac{H}{v} \times 2 \tag{2}$$

In this formula Q is the numbers of people in the vehicle, its value is 225 here; q is the numbers of people that transit by the high-altitude operation truck every time, its value would be 14 if every square meter can stand 9 people in the platform; H is the working height, its value is 8 here; v is the average lifting speed, its value is 20m/min here.

According to the formula (2), it would need 774 seconds that 225 people evacuate from the vehicle.

The passengers are in a open platform when they are transferred by the high-altitude operation truck, so the safety of this evacuation facilities is a bit poor than others. Due to the high-altitude operation truck only can evacuate part of passengers in the vehicle, the scene in evacuating easily disorder. Then professionals are needed to organize. This increases the difficulty of the operation. The high-altitude operation truck need professional operation person to drive, this increased the dependence on outside conditions, and reduce the timeliness of passenger evacuation.

C The Flexible Slip Pocket

There are some date show that the price of The flexible slip pocket used for high-rise is 12 thousands RMB per meter. The flexible slip pocket used for hanging monorail sky train system is simpler than that used for high-rise, its price is about 8 thousands RMB per meter. The total length of the flexible slip pocket needed is about 16m, the construction of the total cost would be one hundred and thirty thousand RMB.

The flexible slip pocket placed in a sealed box at ordinary times, its maintenance and management cost is about 1000 RMB a year.

When passengers evacuate by the flexible slip pocket, rescuers on the ground can control passengers' slip velocity by adjusting the Angle between the car floor and decline period. To make passengers slide smooth, the internal surface of the flexible slip pocket needs to have certain smoothness. Assumes that the average friction coefficient is 0.2, and the time interval between passengers is 2s, the time that all passengers evacuated from the vehicle used can be calculated by the following formula:

$$T = \sqrt{\frac{2S}{g\sin\theta - \mu g\cos\theta}} + 2(Q-1) \tag{3}$$

In this formula S is the length of the incline section in a flexible slip pocket, its value is 14m here; g is the local acceleration of gravity, its value is 9.8m/s^2; θ is the dip angle, its value is 35°here; μ is the friction coefficient, its value is 0.2 here; Q is the numbers of people in the vehicle, its value is 225 here.

According to the formula (3), it would need 456 seconds that 225 people evacuate from the vehicle.

Passengers can slide in a semi-enclosed space when evacuate by this kind of evacuation equipments, the safety of this evacuation facilities is good. However, passengers are not familiar with this kind of equipment, increase the difficulty of organization and operation. And the flexible slip pocket need professional rescuers on the ground to participate in to complete the passenger evacuation, have high dependency on the outside condition.

IV. Comprehensive Evaluation on Sky Train Passenger Landing Facilities

A Evaluation System

Set up an evaluation system about sky train passenger landing facilities as shown in figure 3. The system is mainly divided into three aspects, they are economic performance, timeliness performance and practical

performance.

Economic performance means the capital investment of sky train passenger landing facilities, includes the initial construction investment and maintenance charge. Timeliness performance includes evacuation efficiency and the advance rate of rescue work. Practical performance includes safety, difficulty about organization and operation and the performance about dependency on outside condition.

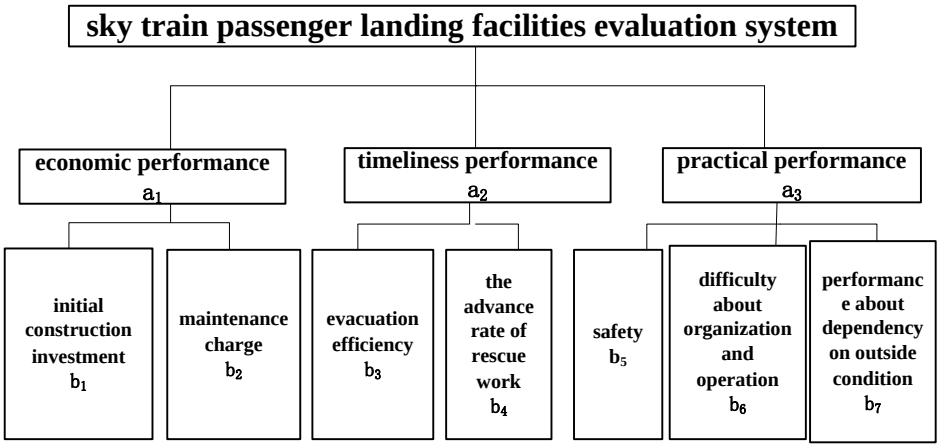

Fig.3 The sky train passenger landing facilities Evaluation system

B Comprehensive Evaluation Model

According to the Secondary evaluation system established above, method of nine marks is used to determine the level of the relative importance of indicators, and the corresponding judgment matrix was constructed.

The economic performance, timeliness performance and practical performance is the first level of assessment criteria about the sky train passenger landing facilities evaluation system. The judgment matrix is constructed as following according to these three indicators' relative important degree.

$$A_1=\begin{bmatrix} 1 & 1/3 & 1/3 \\ 3 & 1 & 1 \\ 3 & 1 & 1 \end{bmatrix} \tag{4}$$

The numbers in the matrix are the relative important degree of the economic performance, timeliness performance and practical performance. The weights can be calculated by the following formula:

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}\left(i=1,2,\cdots,n\right) \tag{5}$$

In this formula w_i is the relative weights, a_{ij} and a_{kj} are corresponding element in the judgment matrix.

The relative weight of each index can be calculated by formula (5), then the weight vector W_1 = (0.1428 0.4286 0.4286)^T is established. Implements matrix consistency inspection by formula (6) :

$$\begin{cases} \lambda_{\max} = \dfrac{1}{n}\sum_{i=1}^{n}\dfrac{\sum_{j=1}^{n} a_{ij} w_j}{w_i} \\ C_I = \dfrac{\lambda_{\max} - n}{n-1} \\ C_R = \dfrac{C_I}{R_I} \end{cases} \tag{6}$$

$\lambda_{\max}$ is the largest eigenvalue of the judgment matrix; n is the dimension of the judgment matrix; a_{ij} is the corresponding element in judgment matrix; w_i, w_j are the corresponding element of weight vector; C_I is consistency index of judgment matrix; C_R is consistency ratio index of the judgment matrix; R_I is random consistency index, it is generally given by practical experience, the values are shown in table 2[6].

According to formula (6) the consistency ratio index of the matrix A_1 C_R=0<0.1, so matrix A1 satisfies the requirement of consistency check.

Table 2 the value of R_I

Dimension n	3	4	5
R_I	0.58	0.90	1.12

The weight of index in first level was calculated and its value was shown in table3.

Table 3 he weight of index in first level

	a_1	a_2	a_3	weight
a_1	1	1/3	1/3	0.1428
a_2	3	1	1	0.4286
a_3	3	1	1	0.4286

In a similar way, the relative weights of economic performance, timeliness performance and practical performance was calculated and shown in table 4-6. According to the result shown in table 3-6, the weights of evaluation index at all levels in the system were obtained, as shown in table 7.

Table 4 The relative important degree and weight of economic performance

	b_1	b_2	weight
b_1	1	7	0.8750
b_2	1/7	1	0.1250

Table 5 The relative important degree and weight of timeliness performance

	b_3	b_4	weight
b_3	1	1/3	0.25
b_4	3	1	0.75

Table 6 The relative important degree and weight of practical performance

	b_5	b_6	b_7	weight
b_5	1	5	3	0.6333
b_6	1/5	1	1/3	0.1062
b_7	1/3	3	1	0.2605

Table 7 the weights of evaluation index at all levels in the sky train passenger landing facilities Evaluation system

Index in the first level	weight	Index in the second level	weight	Weight to the sky train passenger landing facilities Evaluation system
a_1	0.1428	b_1	0.8750	0.1249
		b_2	0.1250	0.0179
a_2	0.4286	b_3	0.25	0.1072
		b_4	0.75	0.3214
a_3	0.4286	b_5	0.6333	0.2714
		b_6	0.1062	0.0455
		b_7	0.2605	0.1117

B Analysis of the Example

Due to the unit of index is various, they should be unified before being put together. According to above analysis, the classification standards of the economic performance and evacuation efficiency can be obtained, as shown in table 8.

The economic performance and evacuation efficiency can be transformed to 10-point scale score by formula (7). For the rest of the indicators can be scored in accordance with a 10-point scale, the results are shown in table 9.

$$y = y_{j+1} + \frac{x_{i+1} - x}{x_{i+1} - x_i} \times (y_j - y_{j+1}) \tag{7}$$

In the formula, x is the measured values of indexes. x_i and x_{i+1} are the lower limit and upper limit of the interval which classed by index measured values, and $x \in [x_i, x_{i+1}]$; y is the score of index; y_j and y_{j+1} are the lower limit and upper limit of the interval which classed by index scores.

Table 8 the classification standards of the economic performance and evacuation efficiency

evaluation index	the classification standards of the economic performance and evacuation efficiency				
	8~10	6~8	4~6	2~4	0~2
initial construction investment /10 thousands RMB	0~5	5~10	10~15	15~20	>20
Maintenance charge/(CNY·year)	0~500	500~1000	1000~1500	1500~2000	>2000
evacuation efficiency /s	0~300	300~600	600~900	900~1200	>1200

Table 9 the scores of all indexes

Evaluation index	independent staircases	high-altitude operation truck	flexible slip pocket
initial construction investment	6.4	2	4.8
Maintenance charge	6.8	2	6
evacuation efficiency	8.64	4.84	6.96
advance rate of rescue work	6	7	7
safety	9	8	9
difficulty about organization and operation	9	7	8.5
performance about dependency on outside condition	6	7	7

Each Weight to the sky train passenger landing facilities Evaluation system multiplied by the corresponding evaluation index score respectively, and the sum of them is the comprehensive score for this kind of evacuation facilities. The comprehensive scores of these three kinds of passenger evacuation facilities studied in this paper are shown in table 10.

Table 10 comprehensive scores of the sky train passenger landing facilities

independent staircases	high-altitude operation truck	flexible slip pocket
7.298	6.326	7.314

V. Conclusion

The performance of independent staircases in economy, efficiency, safety, difficulty degree of organization and operation are good, but this kind of facilities require vehicles can continue to drive in case of accident or failure. It can't ensure passenger evacuation work went timely.

The score of high-altitude operation truck in various evaluation index is below or equal to the other two kinds of evacuation facilities. Its comprehensive score is only 6.326, is the lowest score in these three kinds of evacuation facilities.

Compared with the other two kinds of sky train passenger landing facilities, the score of flexible slip pocket in each evaluation index is balanced. Its comprehensive score is 7.314, is the highest score in these three kinds of evacuation facilities.

There are more or less imperfection in sky train passenger landing facilities studied in this paper. A kind of sky train passenger landing facilities with good economic performance, high evacuation efficiency and good practical performance is badly in need.

VI. Acknowledgements

The author would like to acknowledge the support of the Shanghai University of Engineering Science Innovation Fund for Graduate Students (No. EI-0903-14-01179) and the support of Graduate Student Education Innovation Plan of Shanghai (No. 13sc002).

References

[1] Qin Wu, Analyzed on the applicability of the sky train, Public Utilities, (6), 2012, 17-21.

[2] Li Mao-peng, Research on evacuation mode, escape efficiency and capacity of seismic about high-speed railway long bridge in emergency, Southwest Jiaotong University, ME, 2011.

[3] Xiang Qin, Li Yuan-fu, Study on construction patterns of high speed railway bridge escape routes in mountain regions, China Safety Science Journal, 23(5), 2013, 101-107.

[5] GB50157-2013, Code for the design of metro.

[6] Zhou Gang, Lu Jing, Application of analytic hierarchy process for mode selection of Chongqing rail transit line 4, Urban Mass Transit, 15(9), 2012, 58-62.