ELSEVIER
Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Engineering 15 (2011) 4558 – 4562
Procedia Engineering
www.elsevier.com/locate/procedia

Safety evaluation of urban transit signal system based on the improved TOPIS

Jiliang Tu* , Qiuxiang Tao , Qian Deng
School of information Engineering, Nanchang Hangkong University, Jiangxi, 330063, China

Abstract

Safety evaluation is one of the most effective countermeasures to improve the safety in modern urban transit system. This paper now applies that method to get the order preference of safety in all fault modes in a urban transit signal system using TOPIS based entropy weight for safety evaluation. TOPSIS is based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). Entropy weight is ascertained by entropy theory, and the subjectivity in ascertaining the weights of more factors in lower hierarchy is avoided. The evaluation result indicates that this method is easy and can be implemented as an effective method in safety evaluation of urban transit signal system.

Keywords: Safety evaluation; urban transit signal system; entropy wight method; TOPIS

1. Introduction

Safety risk evaluation is one of the most effective countermeasures to improve the safety in modern urban transit system, which is a multiple criteria decision making (MCDM) problem, and the rail traffic signal control system generally, as distinct from others, are of extraordinary requirement on safety, replacement, value and so on[1]. In order to evaluate transit signal system, there are two aspects that need to be solved. The first is to establish an evaluation model, and the second is to select an evaluation method. So far several evaluation methods have been reported[2-3], such as the Delphi technique, the analytical hierarchy process(AHP), the principal component analysis (PCA), etc. However, these defects in the above methods lie either in biased opinions or incomplete manifestation of details. Therefore, in this paper, we summary and develop some specialized criteria for evaluating safety degree of transit signal system according to engineering practice and a questionnaire survey. Compared with some methods, this paper proposes a comprehensive evaluation method based on information entropy weight (IEW) and Technique for order preference by similar-it to ideal solution (TOPIS) [4-5]. We attempt to use the information entropy weight to obtain the weight objectively, and apply the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method to fully and objectively evaluate Transit signal

* Corresponding author. Tel.:+8613576276460
E-mail address: tujiliang@yahoo.com.cn

doi:10.1016/j.proeng.2011.08.856

system. An improved evaluation method was established and applied in a case study. Our results revealed that IEW and TOPSIS are suitable for the application in the research of the safety evaluation for transit signal system.

The rest of the paper is organized as follows: in the following section, we briefly introduce the methodology of improved TOPSIS method and emphasize the importance of weighing mechanism. In Section 3, we illustrate the proposed approach with a real example in terms of our questionnaire studies.The final section concludes.

2. Methodology of the improved TOPIS method

2.1. Normalization of the evaluation matrix

Assuming x_{ij} was the evaluation matrix X of alternative i under evaluation index j, an element x_{ij} of the normalized evaluation matrix X could be calculated by many normalization methods to achieve this objective. $X^{'} = (x_{ij}^{'})_{m\times n}$, is the matrix after range standardization; $\max\limits_{1\le j\le n} x_{ij}$, $\min\limits_{1\le j\le n} x_{ij}$ is the maximum and the minimum value in evaluation index j respectively, the value of $X^{'}$ is $0 \le x_{ij}^{'} \le 1$.

$$x_{ij}^{'} = \frac{x_{ij} - \min\limits_{1\le j\le n} x_{ij}}{\max\limits_{1\le j\le n} x_{ij} - \min\limits_{1\le j\le n} x_{ij}} \qquad (1)$$

2.2. Calculating indices weight by IEW

So according to matrix $X^{'} = (x_{ij}^{'})_{m\times n}$, we calculated the information entropy using:

$$E_j = -(\sum_{i=1}^{m} f_{ij} \ln f_{ij}) \quad i = 1,2,\ldots,m; j = 1,2,\ldots,n \qquad (2)$$

In order to avoid the insignificance of $\ln f_{ij}$, we stipulated: $f_{ij} = \dfrac{1 + x_{ij}^{'}}{\sum_{i=1}^{m}(1 + x_{ij}^{'})}$ (3)

Next, the weight w_j is defined as: $w_j = (1 - E_j) / \sum_{j=1}^{n}(1 - E_j)$ (4)

2.3. Constructed the weighted normalized decision matrix

Multiply the columns of the normalized decision matrix by the associated weights. The weighted and normalized decision matrix is obtained as formula (5), and the index j weight $W = (w_1, w_2, \ldots w_n)$ is determined by the IEW (2.2 Step).

$$V = (v_{ij})_{m\times n} = \begin{bmatrix} w_1 x'_{11} & w_2 x'_{12} & \dots & w_n x'_{1n} \\ w_1 x'_{21} & w_2 x'_{22} & \dots & w_n x'_{2n} \\ \dots & \dots & \dots & \dots \\ w_1 x'_{m1} & w_2 x'_{m2} & \dots & w_n x'_{mn} \end{bmatrix} \quad (5)$$

2.4. Determining the positive and negative ideal solutions

This step could get V^+ and V^- to be the basis to calculate the distances. The PIS V^+ indicates the most preferable alternative while the NIS V^- indicates the least preferable alternative. The formulas are as follows:

$$V^+ = (\max_{1\le i\le m} v_{i1}, \max_{1\le i\le m} v_{i2}, \dots, \max_{1\le i\le m} v_{in}) \quad ; V^- = (\min_{1\le i\le m} v_{i1}, \min_{1\le i\le m} v_{i2}, \dots, \min_{1\le i\le m} v_{in}) \quad (6)$$

2.5. Calculating the separation measure

The n-indices evaluation distance can measure the separation from the PIS and NIS for each alternative.

$$d_i^+ = (\sum_{j=1}^{n} (v_{ij} - v_j^+)^2)^{\frac{1}{2}} \quad ; d_i^- = (\sum_{j=1}^{n} (v_{ij} - v_j^-)^2)^{\frac{1}{2}} \qquad i = 1,2,\dots,m \quad (7)$$

2.6. Calculating the relative closeness to the ideal solution

The relative closeness of the i th alternative with respect to the ideal solution V^+ is defined as C_i .

$$C_i = d_i^- / (d_i^+ + d_i^-) , \quad i = 1,2,\dots,m \quad (8)$$

2.7. Ranking the priority

Then a set of alternatives can then be ranked according to the descending order of C_i .When an evaluation system consists of multi-hierarchy indices, a multi-hierarchy synthetic evaluation needs to be carried out based on the single hierarchy. The evaluation matrix data of superior-hierarchy consist of the C_i values in an inferior-hierarchy evaluation system, and identifies the relative importance of the attributes associated with a service or product while indicating the degree of performance at the same time.

$$\sum c_i = AC \quad (9)$$

3. Case study of transit signal system

3.1. Evaluation aspects and indices

In signal control system, the safety-critical device (which means a fault or failure in the device can cause a collision, derailment of equipment and other hazardous situation) should be identified by using strictly hazard analysis or other analytical methods for identification. Potential fault modes of the signal control system classifies generally five categories: Hardware failures and system resources error(E1), Basic data error(E2), System internal communication error(E3), External communication system error(E4), External communication system failures(E5). The problem of a typical multiple indices evaluation method is to focus on a set of feasible alternatives and to consider more than one index for priority ranking. Considering these principles and some practical conditions from literatures, the indices included two hierarchies, three aspects and 9 evaluation indices. The three aspects are impact and consequences of equipment failure factor endowment(A1), equipment factor itself endowment (A2), maintenance factor endowment (A3) and the three aspects are further divided into the impact of failure on the environment safety and man(B1), The impact of failure on the system function(B2), The impact of failure on the relative equipment(B3), failure frequency(B4), failure loss(B5), fault detectability(B6), the number of backup equipment(B7), maintenance costs(B8) , maintenance time(B9). Decision maker can give a score depend on the importance of each evaluation set individually using a numerical scale, typically ranging from 10 to 100. These scales, however, can vary in range depending on the each grade standard being applied. The details of which are given in Table 1.

Table 1 Data of each endowment (A1,A2,A3) in transit signal system

Failure mode	A1(0.682)			A2(0.103)				A3(0.215)	
	B1(0.363)	B2(0.318)	B3(0.318)	B4(0.25)	B5(0.249)	B6(0.25)	B7(0.251)	B8(0.49)	B9(0.51)
E1	80	80	70	25	90	70	80	75	70
E2	85	90	60	10	85	75	45	70	85
E3	95	100	60	15	75	60	80	80	80
E4	80	80	75	20	80	60	60	90	95
E5	90	95	70	30	90	50	90	95	90

3.2. Calculation results

We calculated the weights of indices of impact and consequences of equipment failure factor endowment according to the raw data in Table 1 and the formulas (1)-(4), as well as the distances from the positive and negative ideal solution (d^+ and d^-) and the relative closeness to the ideal solution (c_i) according to the raw data in Table 1 and the formulas (5)-(8) (Table 2).

Likewise, the indices weight w_j according to the formulas (1)-(4) and the raw data in Table 1, as well as (d^+ , d^- and c_i) for each fault mode on remaining aspects (equipment factor itself endowment (A2), maintenance factor endowment (A3)) based on the formulas (5)-(8) were also calculated. Rankings of 5 fault modes were based on their c_i values. In this paper ,the weight of each factor in the first lever is determined by AHP Method , so the general rankings of 5 fault modes were based on the value of $\sum c_i$ according to the formulas (9)(Table 3).

Table 2 d^+, d^-, c_i and ranking order of endowment (A1)

Failure mode	d^+	d^-	c_i	$Rank$
E1	0.494	0.21	0.298	5
E2	0.431	0.2	0.317	4
E3	0.32	0.482	0.6	2
E4	0.482	0.32	0.399	3
E5	0.202	0.399	0.664	1

Table 3 ranking order of c_i, $\sum c_i$ in each fault mode

Failure mode	A_1	A_2	A_3	$\sum C_i$	$Rank$
E1	0.298	0.795	0.135	0.314	5
E2	0.317	0.455	0.369	0.342	4
E3	0.6	0.309	0.4	0.527	2
E4	0.32	0.531	0.878	0.516	3
E5	0.399	0.634	0.55	0.636	1

4. Conclusion

As the results shown in the application example, we find that the proposed method is practical for ranking transit signal system health level in terms of their overall performance with respect to indices. Simultaneously, we believe that there is room for future enhancements and validation of the approach presented. For example, how to extend the current proposed approach to handle the inherent uncertainty and imprecision of the human decision making process should be examined. This may be improved in future development.

Acknowledgements

The project was supported by the National Natural Science Foundation of China (No. 60973048) and Youth Natural Science Foundation of Jiangxi Province (No.GJJ11175). The authors express sincere appreciation to the anonymous referees for their helpful comments to improve the quality of the paper.

References

[1]Armin Z., Günter H.. A train control system case study in model-based real time system design. In International parallel and distributed processing symposium, IEEE [C]. 2003, 118-126.

[2] YANG Yu-zhong, WU Li-yun. TOPSIS based on entropy weight for safety evaluation on coalmine transportation system. JOURNAL OF HARBIN INSTITUTE OF TECHNOLOGY 2009,41(11):229

[3] Hong Zhang , Chao-lin Gu , Lu-wen Gu , Yan Zhang . The evaluation of tourism destination competitiveness by TOPSIS & information entropy - A case in the Yangtze River Delta of China. Tourism Management, 32 (2011): 443-451

[4] LI Chang-you, XU Min-qiang. Criticality analysis of equipment based on the improved TOPSIS. JOURNAL OF V IBRATION AND SHOCK,2009,28(6):165-168.

[5]Jianrong Wang, Kai Fan, Wanshan Wang. Integration of fuzzy AHP and FPP with TOPSIS methodology for aeroengine health assessment. Expert Systems with Applications, 37 (2010): 8516 – 8526