TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.5, May 2014, pp. 4101 ~ 4106
DOI: http://dx.doi.org/10.11591/telkomnika.v12i5.5121

Evaluation Methods of Multidimensional Comfort for High-speed Train Based on FANP

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Abstract

Aiming at the problems of multidimensional comfort for high-speed train, on the base of systematic analysis of mutual effects among evaluation indexes, the comprehensive evaluation methods of multidimensional comfort for high-speed train based on Fuzzy-ANP have been established by fuzzy theories and network hierarchy analysis. The weight of calibrated evaluation indexes can be calculated by the hierarchy structure and judgment matrix of evaluation indexes. Meanwhile, the quantitative value of comfort indexes can be determined according to the effect on the comfort for high-speed train. The fuzzy evaluation matrix can be established and the evaluation value of comfort for high-speed train can be achieved to realize the calibration of comfort level. Though the example analysis, the effectiveness of the methods can be further proved and the strong theory support can be provided for the comfort evaluation for high-speed train.

Keywords: *fuzzy theory, ANP, high-speed train, evaluation of comfort*

1. Introduction

With the advent of the era of high-speed rail ,people pay more and more attention to the train ride comfort during the running when they pay attention to the high speed train running speed.Compared with the traditional trains,high-speed train equipped with full sealed structure,the running performance of the train,air quality and the common decoration environment of the train act the roles of various indexes that affect the ride comfort of passengers [1]. So it is necessary to study a comprehensive evaluation for the comfort of high-speed train [2].

Evaluation of complex systems at home and abroad mainly using analytic hierarchy process (AHP) as the method for determining the index weights.AHP is based on a premise that there is no interaction between the system elements in different layers and the same layer and makes the final result distortional. For multiple weighting, the subjective uncertainty of policymakers will affect the objectivity and authenticity of the evaluation results of system [3-6]. So we combine the fuzzy theory and ANP to build evaluation model of high-speed trains's comfort based on Fuzzy Analytic Network Process (FANP) according to the characteristic of high-speed trains's operating environment in order to evaluate the comfort of high-speed trains objectively and accurately.

2. Evaluation Model

ANP, developed on the basis of AHP,is a decision-making method which mainly focused on decision-making problems with structure of feedback and dependence [7]. After the target of decision making problem is determined, ANP elements can be divided into control layer and network layer. The control layer contains the decision criteria of decision problems and the network layer contains is the group of elements dominated by the control layer which influence each other between different groups [8].

Received November 5, 2013; Revised December 27, 2013; Accepted January 20, 2014

2.1. The Determination of Index Weights

(1) Constructing judgment matrix R. Set A as the target of decision making problem,set $P_1, P_2, ..., P_n$ as elements of the control layer,set $B_1, B_2, ..., B_n$ as elements of the network layer.,elements group B_i contains indicators $B_{i1}, B_{i2}, ..., B_{in}$. Set elements of the control layer $P_s(s=1,2,...,n)$ as the first criterion and index of network layer elements group $B_{il}\,(l=1,2,...,n)$ as the second criterion, we use $1\sim 9$ quantitative scale method professor Saaty proposed quantify the importance of pairwise comparison of multiple indicators in element group B_i in order to construct judgment matrix $R=(r_{ij})_{n\times n}$.

(2) Solving super-matrix W. We can get the eigenvectors which is the weight vector of judgment matrix R and super-matrix W according to eigenvalue method.

(3) Constructing weighted super-matrix $\overline{W}$. Set elements of the control layer $P_s(s=1,2,...,n)$ as the first criterion and index of network layer elements group $B_{il}\,(l=1,2,...,n)$ as the second criterion. Compare the effects between elements groups to get judgment matrix A. We can get the eigenvectors of judgment matrix A According eigenvalue method and get weighted matrix $\overline{A}$. Then weight elements of super-matrix W to get weighted super-matrix $\overline{W}$, then $\overline{W}=\overline{A}W$.

(4) Determining weight $W(i)$ .If the limit of weighted super-matrix $\overline{W}^{\infty}=\lim_{k\to\infty}\overline{W}^k$ exists we can get weights of multiple indicators by calculating according to the formula.

$$W(i)=\lim_{k\to\infty}\left(1/n\right)\sum_{k=1}^{n}\overline{W}^k \quad \left(i=1,2,...,n\right).$$

2.2. Constructing Evaluation Matrix

Determine the degree of multiple indicators’s influencing comfort of high-speed trains by constructing fuzzy evaluation matrix [9]. First, construct comment set of comfort of high-speed train [10], as shown in Table 1. Then, we evaluate the multiple indicators in order to get fuzzy evaluation matrix of multiple indicators of each element group $E_k=(e_{ij})_{m\times n}\ (i=1,2,..., \ n; j=1,2,...,n)$ according to the comment set by using the expert scoring method, in the $E_k=(e_{ij})_{m\times n}\ (i=1,2,...,n; j=1,2,...,n)$: k represents the number of element groups of the decision making problem, m represents the number of indicators within the elements group, n represents the number of levels of comment set, e_{ij} represents membership degree of evaluating indicators in elements group as V_j, it also can be said that e_{ij} represents experts proportion number of evaluating the ith indicator as the jth grade.

Table 1. Comment Set of Comfort of High-speed Train

Quantized value V_j	Evaluation feature
0.1	Slightly affected
0.3	Less affected
0.5	Generally affected
0.7	Greatly affected
0.9	Very greatly affected

2.3. Comprehensive Evaluation Process

According to multiple indicators weights and fuzzy evaluation matrix, comprehensive evaluation procedure of high-speed train comfort as follows:

(1) Solving evaluation matrix of each elements group $B_i(i=1,2,...,n)$, $B_k=W_{km}E_k$, k represents the number of element groups of the decision making problem, m represents the number of indicators within the elements group. W_{km} represents weights of multiple indicators.

(2) Solving evaluation matrix of each criteria $P_s(s=1,2,...,n)$, $P_k=W_{kn}D_{kn}$, k represents the number of criteria of the decision making problem, n represents the number of elements groups of each criteria, W_{kn} represents weights of multiple indicators of elements groups. $D_{kn}=(B_1,B_2,...,B_n)$.

(3) Solving evaluation matrix of the target A, $A=W_kQ_k$, k represents the number of criteria of the decision making problem, W_k represents weight of criteria layer, $Q_k=(P_1,P_2,...,P_k)$.

(4) Evaluation of comfort of high-speed train. Evaluation value of comfort of high-speed train Can be represented as: $f = AV$, V represents evaluation grade row vector in evaluation set, $V = (0.1, 0.3, 0.5, 0.7, 0.9)$.

Grade of comfort of high-speed train can be determined as Table 2 according to the size of evaluation value f of high-speed trains comfort.

Table 2. Grade of Comfort of High-speed Train

Evaluation Value f	Comfort levels
[0.8,1.0)	Very uncomfortable
[0.6,0.8)	Less comfortable
[0.4,0.6)	Generally comfortable
[0.2,0.4)	More comfortable
[0,0.2)	Very comfortable

3. The Example Analysis

Xi'an to Zhengzhou section of high speed train is taken as an example in the literature [11], the typical multiple indicators are chosen to be analyzed in this article to build evaluation system of multiple index of high-speed train comfort, as shown in Table 3.

Table 3. Multiple Index Evaluation System of Comfort of High-speed Train

Targets	Criterion level	Multiple Indicators
Multiple index evaluation system	Operating performance B_1	Operating oscillation B_{11}
		Operating smoothness B_{12}
	Operating performance B_2	The temperature inside the car B_{21}
		The humidity inside the car B_{22}
		Air cleanliness B_{23}
	Operating performance B_3	Seating comfort B_{31}
		The lighting inside the car B_{32}

3.1. Determining Index Weights

Constructing ANP network structure as Figure 1 according relationship between high-speed train comfort multiple indicators.

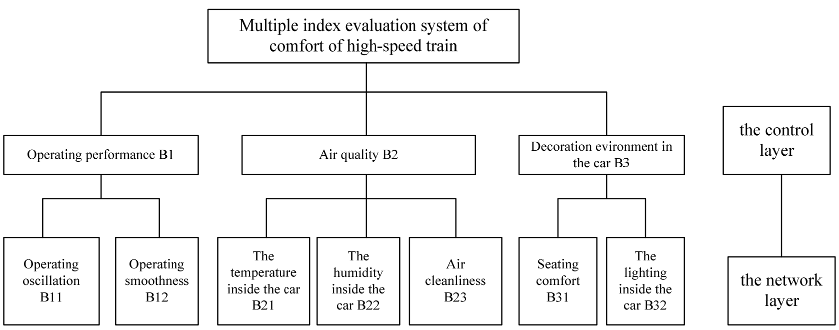

Figure 1. ANP Network Structure of Multiple Indicators of Ccomfort of High-speed Train

(1) Constructing judgment matrix

As an example of the operating performance B_1 , $1 \sim 9$ scale method proposed by Professor Saaty is adopted to construct judgment matrix as Table 4-Table 7.

Table 4. Judgment Matrix1

B_{11}	B_{21}	B_{22}	B_{23}	Weights
B_{21}	1	2	1/2	0.286
B_{22}	1/2	1	2	0.143
B_{23}	2	1/2	1	0.571

Table 5. Judgment Matrix2

B_{12}	B_{21}	B_{22}	B_{23}	Weights
B_{21}	1	2	2	0.5
B_{22}	1/2	1	2	0.25
B_{23}	1/2	1/2	1	0.25

Table 6. Judgment Matrix3

B_{11}	B_{31}	B_{32}	Weights
B_{31}	1	3	0.75
B_{32}	1/3	1	0.25

Table 7. Judgment Matrix4

B_{12}	B_{31}	B_{32}	Weights
B_{31}	1	4	0.8
B_{32}	1/4	1	0.2

(2) Constructing weighted super-matrix ,super-matrix and limiting super-matrix

The software Super Decision is used in this article to obtain weighted matrix w , super-matrix w , limiting super-matrix $\overline{w}^{\infty}$ of multiple index evaluation system of comfort of high-speed train. So as follows:

$$W=\begin{bmatrix} 0 & 1 & 0.5 & 0.667 & 0.75 & 0.833 & 0.667 \\ 1 & 0 & 0.5 & 0.333 & 0.25 & 0.167 & 0.333 \\ 0.333 & 0.493 & 0 & 0.667 & 0.333 & 0.594 & 0.612 \\ 0.333 & 0.311 & 0.667 & 0 & 0.667 & 0.249 & 0.209 \\ 0.334 & 0.196 & 0.333 & 0.333 & 0 & 0.157 & 0.179 \\ 0.75 & 0.8 & 0.167 & 0.667 & 0.2 & 0 & 1 \\ 0.25 & 0.2 & 0.833 & 0.333 & 0.8 & 1 & 0 \end{bmatrix} \overline{W}=\begin{bmatrix} 0 & 0.637 & 0.167 & 0.222 & 0.25 & 0.278 & 0.222 \\ 0.637 & 0 & 0.167 & 0.111 & 0.083 & 0.056 & 0.111 \\ 0.086 & 0.127 & 0 & 0.222 & 0.111 & 0.198 & 0.204 \\ 0.086 & 0.08 & 0{,}222 & 0 & 0.222 & 0.083 & 0.07 \\ 0.086 & 0.051 & 0.111 & 0.111 & 0 & 0.052 & 0.06 \\ 0.079 & 0.084 & 0.055 & 0.222 & 0.067 & 0 & 0.333 \\ 0.026 & 0.021 & 0.278 & 0.111 & 0.267 & 0.333 & 0 \end{bmatrix} \overline{W}^{\infty}=\begin{bmatrix} 0.257 & 0.257 & 0.257 & 0.257 & 0.257 & 0.257 & 0.257 \\ 0.221 & 0.221 & 0.221 & 0.221 & 0.221 & 0.221 & 0.221 \\ 0.126 & 0.126 & 0.126 & 0.126 & 0.126 & 0.126 & 0.126 \\ 0.101 & 0.101 & 0.101 & 0.101 & 0.101 & 0.101 & 0.101 \\ 0.071 & 0.071 & 0.071 & 0.071 & 0.071 & 0.071 & 0.071 \\ 0.111 & 0.111 & 0.111 & 0.111 & 0.111 & 0.111 & 0.111 \\ 0.113 & 0.113 & 0.113 & 0.113 & 0.113 & 0.113 & 0.113 \end{bmatrix}$$

According to the limiting super-matrix $\overline{w}^{\infty}$, weight value of multiple indicators of comfort of high-speed train is as shown in Table 8.

Table 8. Weight Value of Multiple Indicators of Comfort of High-speed Train

Targets	Criterion level	Weights	Multiple Indicators	Weights
Multiple index evaluation system	B_1	0.478	B_{11}	0.257
			B_{12}	0.221
	B_2	0.298	B_{21}	0.126
			B_{22}	0.101
			B_{23}	0.071
	B_2	0.224	B_{31}	0.111
			B_{32}	0.113

3.2. Constructing Evaluation Matrix

According to the degree of high-speed trains comfort influenced by multiple indicators and comment set, expert scoring method is adopted to obtain the fuzzy evaluation of multiple indicators within each element group,as shown in Table 9.

Tab.9 Fuzzy evaluation table of multiple indicators of comfort of high-speed train

Indicator	Slightly Affected	Less Affected	Generally Affected	Greatly Affected	Very greatly Affected
B_{11}	0.01	0.03	0.06	0.13	0.77
B_{12}	0.03	0.08	0.12	0.26	0.51
B_{21}	0.03	0.11	0.15	0.34	0.37
B_{22}	0.05	0.09	0.03	0.21	0.62
B_{23}	0.03	0.04	0.11	0.37	0.45
B_{31}	0.01	0.04	0.07	0.22	0.66
B_{32}	0.02	0.11	0.17	0.21	0.49

Fuzzy evaluation matrix E_k of multiple indicators is as follows:

$$E_1=\begin{bmatrix}0.01 & 0.03 & 0.06 & 0.13 & 0.77\\ 0.03 & 0.08 & 0.12 & 0.26 & 0.51\end{bmatrix}\quad E_2=\begin{bmatrix}0.03 & 0.11 & 0.15 & 0.34 & 0.37\\ 0.05 & 0.09 & 0.03 & 0.21 & 0.62\\ 0.03 & 0.04 & 0.11 & 0.37 & 0.45\end{bmatrix}\quad E_3=\begin{bmatrix}0.01 & 0.04 & 0.07 & 0.22 & 0.66\\ 0.02 & 0.11 & 0.17 & 0.21 & 0.49\end{bmatrix}$$

3.3. Comprehensive Evaluation

According to the formula $B_k = W_{km}E_k$, the evaluation matrix of each element group is obtained, so as follows：

$$B_1 = W_{12}E_1 = (0.257, 0.221)\begin{bmatrix}0.01 & 0.03 & 0.06 & 0.13 & 0.77\\ 0.03 & 0.08 & 0.12 & 0.26 & 0.51\end{bmatrix} = (0.0092,0.0254,0.0419,0.0909,0.3106)$$

$$B_2=W_{23}E_2=(0.126,0.101,0.071)\begin{bmatrix}0.03 & 0.11 & 0.15 & 0.34 & 0.37\\ 0.05 & 0.09 & 0.03 & 0.21 & 0.62\\ 0.03 & 0.04 & 0.11 & 0.37 & 0.45\end{bmatrix}=(0.011,0.0258,0.0297,0.0903,0.1412)$$

$$B_3=W_{32}E_3=(0.111,0.113)\begin{bmatrix}0.01 & 0.04 & 0.07 & 0.22 & 0.66\\ 0.02 & 0.11 & 0.17 & 0.21 & 0.49\end{bmatrix}= (0.0034,0.0169,0.027,0.0481,0.1286)$$

According to the formula $A = W_kQ_k$, the evaluation matrix of target A is obtained, so as follows:

$$A=W_3Q_3=(0.478,0.298,0.224)\begin{bmatrix}0.0092 & 0.0254 & 0.0419 & 0.0909 & 0.3106\\ 0.011 & 0.0258 & 0.0297 & 0.0903 & 0.1412\\ 0.0034 & 0.0169 & 0.027 & 0.0481 & 0.1286\end{bmatrix}=(0.0084,0.0337,0.03345,0.0811,0.2194)$$

According to the formula $f = A\cdot V$, the value of evaluation of the high-speed train comfort is obtained, so as follows:

$$f = A\cdot V = (0.0084,0.0337,0.03345,0.0811,0.2194)\begin{bmatrix}0.1\\ 0.3\\ 0.5\\ 0.7\\ 0.9\end{bmatrix} = 0.2826$$

According to the value $f = 0.2826$ of evaluation of the high-speed train comfort, comprehensive evaluation of high-speed train comfort is "More comfortable". While the High-speed train running performance will be improved in the future, the accuracy of valuation of the high-speed train comfort should be improved in many aspects.

4.Conclusion

A comprehensive evaluation and research of the high-speed train comfort is a systematic project. In this article,through the analysis of fuzzy network level, comprehensive multiple evaluation model of comfort of high-speed train is established. This method not only solves the problem of deviating from the actual situation where AHP is used to obtain the evaluation results, but also overcomes the subjective uncertainty since the introduction of fuzzy theory, which provides a strong theoretical support for the research of high-speed train comfort evaluation.

Acknowledgements

This work was supported by the Natural Science Foundation of Gansu (No:1212RJZA 055).

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