Weights Determination Based on Combined Objective and Subjective Method in Traffic Safety Evaluation

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Abstract: This paper suggests an evaluation index system which combines qualitative indexes and quantitative indexes for road traffic safety evaluation. Considering the drawbacks of some generally used weights determination approaches, this paper proposes a new approach for assessing a certain road traffic safety situation with quantitative and qualitative options. This approach involves the analytic hierarchy process and least squares distance. In addition, the index weights of the index system for road traffic safety evaluation are determined by this approach. The result shows the validity and accuracy of the suggested model.

Keywords： weights determination approach; evaluation index system; road traffic safety evaluation

1 Introduction

Road traffic safety evaluation is both the description and evaluation of the road safety circumstance and it is also the basic of the road safety condition analysis. To build up an index system for road traffic safety evaluation is the first step in the evaluation process. Based on this, to determine the weights of the indexes is very important for the road traffic safety compositive evaluation. The domestic research has already suggested some index systems for road traffic safety evaluation such as “road safety evaluation index system[1]” and “road safety management evaluation index system[2]”. The generally used weights determination approaches are subjective approaches such as “directly given approach[3]” and “importance ranked approach[3]”. These index systems and weights determination approaches have some drawbacks as follows:

(1) The index systems in existence have only qualitative indexes or quantitative indexes. These index systems can not fully reflect the road safety circumstance.

(2) The generally used weights determination approaches are subjective approaches. According to the lack of experience of the decision-maker, sometimes the results of these approaches would be subjective random.

Based on an index system which has both the qualitative indexes and quantitative indexes, this paper proposes a new weights determination approach, called Analytic Hierarchy Process-the Least Squares Distance Method (AHP-LSDM), for assessing a certain road traffic safety situation. This approach has good maneuverability and adaptability and combines the merits of both subjective and objective approaches.

2 Found the index system for road traffic safety evaluation

The final aim to do road traffic safety evaluation is to reduce the number of traffic accidents and to improve the road safety condition. The characteristics of road traffic accidents are these five as following: 1）cause and effect；2）chance；3）concealment；4）phases；5）complexity [4] . From these characteristics, we can analyze the factors which affect the road safety condition. These factors are basically divided into two parts. One is macro factor which contains population, education, the number of vehicle, the length of road and so on. The other is micro factor which contains human, vehicle, road circumstance and so on.

To assess a certain road traffic safety situation objectively, we should follow six principles to found the index system for road traffic safety evaluation: 1）divide the index system according to systems engineering；2）the indexes must obey the principles of traffic engineering；3）the indexes must can be fairly compared；4）the indexes should fully reflect the road safety circumstance；5）the indexes should be independent；6）the indexes should reflect some characteristics in our own nation.

Table1: index system for road traffic safety evaluation

Aim	Rule layer	first index layer	second index layer
Road traffic safety evaluation	Actuality reflection	The happen rate of traffic accidents	The happen rate count in vehicles
			The happen rate count in human
			The happen rate count in GDP
			The happen rate count in mileage
		The severity degree of traffic accidents	The death rate
			The death/injure rate
			The death count in vehicles
			The death count in human
			The death count in GDP
			The death count in mileage
	Background condition	The probability of traffic accidents	The investment rate
			The level of roads
			The traffic accident descend rate
			The death toll descend rate
		The management level of road traffic safety	The road traffic safety supervise system
			The road traffic safety management level
			The road traffic safety condition
		The analysis level of traffic accidents	The traffic accidents analysis level
			The traffic accidents prevent level
			The traffic accidents rescue level
		The policy level of road traffic safety	The road traffic safety regulate department
			The road traffic safety programming level
			The road traffic safety responsibility
			The road traffic safety education

This paper points out the characteristics of road traffic accidents and analyzes the factors which affect the road safety condition. Considering factors about human, vehicle, road circumstance and management, this paper combines qualitative indexes and quantitative indexes. Based on these, an index system is suggested for road traffic safety evaluation according to indexes determination principles. This index system is mainly divided into two parts such as actuality reflection and background condition. Actuality reflection contains the happen rate of traffic accidents and the severity degree of traffic accidents. Background condition contains the probability of traffic accidents, the management level of road traffic safety, the analysis level of traffic accidents, the policy level of road traffic safety. These 6 indexes found the first index layer of the index system and other 24 more detailed indexes found the second index layer of the index system. The happen rate of traffic accidents, the severity degree of traffic accidents and the probability of traffic accidents are quantitative indexes, and the other three are qualitative indexes. Thus, an index system for road traffic safety evaluation is founded. As table1 shows:

3 Found the weights determination model

3.1 Basic hypothesis

(1) Let the decision-maker give out marks and follow the analytic hierarchy process to count the original weights of the indexes. This paper chooses four people, experts in traffic safety research, as decision-makers.

(2) All weights must be positive, $W_i > 0$

(3) The sum of weights in each layer must be 1, $\sum W_i = 1$

3.2 Modeling process

Assume that $R_i = (r_{i1}, \cdots, r_{im})$ and $R_j = (r_{j1}, \cdots, r_{jm})$ are the original weights of an index layer which has m indexes given by two decision-makers. w_i and w_j are comparatively weights of $R_i = (r_{i1}, \cdots, r_{im})$ and $R_j = (r_{j1}, \cdots, r_{jm})$. Thus, the squares distance is defined[5,6] as follows:

$$d_{ij} = \sqrt{\sum_{k=1}^{m} (w_i r_{ik} - w_j r_{jk})^2} \tag{1}$$

The original weights of an index layer which has m indexes given by n decision-makers are:

$R_i = (r_{i1}, r_{i2}, \cdots, r_{im}), i = 1, 2, \cdots, n$

The comparatively weights are:

$W = (w_1, \cdots, w_n)^{\mathrm{T}}$

To minimize the sum of the squares distance and follow the basic hypothesis, we have:

$$\text{Min } J = \sum_{i=1}^{n} \sum_{j=1, j\neq 1}^{n} d_{ij}{}^2 = \sum_{i=1}^{n} \sum_{j=1, j\neq 1}^{n} \left[\sum_{k=1}^{m} (w_i r_{ik} - w_j r_{jk})^2 \right] \tag{2}$$

$$\text{s.t. } \sum_{i=1}^{n} w_i = 1, w_i \geq 0, i = 1, \cdots, n$$

To solve this equation by Lagrange method, form a Lagrange equation first:

$$L(W, \lambda) = \sum_{i=1}^{n} \sum_{j=1, j\neq 1}^{n} \left[\sum_{k=1}^{m} (w_i r_{ik} - w_j r_{jk})^2 \right] - 2\lambda \left(\sum_{i=1}^{n} w_i - 1 \right) \tag{3}$$

For every $i = 1, \cdots, n$, let $\frac{\partial L}{\partial w_i} = 0$, we have

$$\frac{\partial L}{\partial w_i} = 2 \sum_{j=1, j\neq 1}^{n} \left[\sum_{k=1}^{m} (w_i r_{ik} - w_j r_{jk}) r_{ik} \right] - 2\lambda = 0, i = 1, \cdots, n \tag{4}$$

which can be simplified as

$$(n-1) \left(\sum_{k=1}^{m} r_{ik}^2 \right) w_i - \sum_{j=1, j\neq 1}^{n} \left[\sum_{k=1}^{m} (r_{ik} r_{jk}) \right] w_j - \lambda = 0, i = 1, \cdots, n \tag{5}$$

which can be rewritten in matrix form as

$$GW - \lambda e = 0 \tag{6}$$

$$G=(g_{ij})_{n\times n}=\begin{bmatrix} (n-1)\sum_{k=1}^{m} r_{1k}^2 & -\sum_{k=1}^{m} r_{1k}r_{2k} & \cdots & -\sum_{k=1}^{m} r_{1k}r_{nk} \\ -\sum_{k=1}^{m} r_{2k}r_{1k} & (n-1)\sum_{k=1}^{m} r_{2k}^2 & \cdots & -\sum_{k=1}^{m} r_{2k}r_{nk} \\ \vdots & \vdots & \ddots & \vdots \\ -\sum_{k=1}^{m} r_{nk}r_{1k} & -\sum_{k=1}^{m} r_{nk}r_{2k} & \cdots & (n-1)\sum_{k=1}^{m} r_{nk}^2 \end{bmatrix}$$

To solve this equation with $e^{\mathrm{T}}W=1$, we have

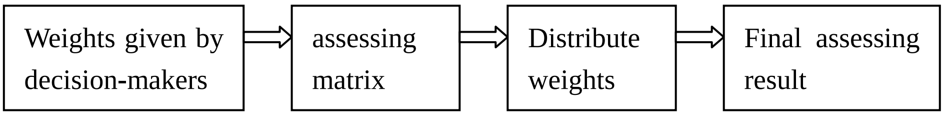
$$W=\frac{G^{-1}e}{e^{\mathrm{T}}G^{-1}e}\geq 0,\quad e=(1,1,\cdots 1) \tag{7}$$

The weights determination results are

$$w=\sum_{i=1}^{n} W_i \cdot R_i,\ i=1,2,\cdots,n \tag{8}$$

W_i is the number i row of W^*.

The modeling process is:



Figer1: modeling process

Thus, a weights determination model has been founded.

4 Determine the weights of the indexes

Let the four experts give out marks of the four indexes in Background condition. And follow the analytic hierarchy process we have the original weights of the indexes.

$$w_{11}=(0.625,0.125,0.125,0.125)$$
$$w_{21}=(0.5817,0.2314,0.1205,0.0664)$$
$$w_{31}=(0.3891,0.1724,0.1215,0.3170)$$
$$w_{41}=(0.5068,0.2168,0.2168,0.0596)$$

Follow the Analytic Hierarchy Process-the Least Squares Distance Method proposed in last section, we have assessing matrix

$$G=\begin{bmatrix} 1.3125 & -0.4158 & -0.3196 & -0.3784 \\ -0.4158 & 1.2326 & -0.3019 & -0.3751 \\ -0.3196 & -0.3019 & 0.8891 & -0.2798 \\ -0.3784 & -0.3751 & -0.2798 & 1.0632 \end{bmatrix}$$

Solve the equation and the final assessing result is

$w_1=(0.5205,0.1870,0.1467,0.1459)$

Follow the same process, the weights of all indexes in the index system for road traffic safety evaluation can be determined. Thus, the final assessing results are

Table2: index weights of the index system for road traffic safety evaluation

Rule layer		first index layer		second index layer	
index	weight	index	weight	index	weight
Actuality reflection	0.625	The happen rate of traffic accidents	0.6	The happen rate count in vehicles	0.3603
				The happen rate count in human	0.1759
				The happen rate count in GDP	0.1545
				The happen rate count in mileage	0.3094
		The severity degree of traffic accidents	0.4	The death rate	0.1978
				The death/injure rate	0.2269
				The death count in vehicles	0.1175
				The death count in human	0.0678
				The death count in GDP	0.1045
				The death count in mileage	0.2855
Background condition	0.375	The probability of traffic accidents	0.5205	The investment rate	0.3029
				The level of roads	0.1542
				The traffic accident descend rate	0.2911
				The death toll descend rate	0.2448
		The management level of road traffic safety	0.1870	The road traffic safety supervise system	0.2741
				The road traffic safety management level	0.2595
				The road traffic safety condition	0.4664
		The analysis level of traffic accidents	0.1467	The traffic accidents analysis level	0.1940
				The traffic accidents prevent level	0.4238
				The traffic accidents rescue level	0.3821
		The policy level of road traffic safety	0.1459	The road traffic safety regulate department	0.2447
				The road traffic safety programming level	0.1872
				The road traffic safety responsibility	0.3326
				The road traffic safety education	0.2355

5 Conclusions

(1) Considering factors about human, vehicle, road circumstance and management, this paper combines qualitative indexes and quantitative indexes and suggests an index system for road traffic safety evaluation according to indexes determination principles..

(2) This paper proposes a new weights determination approach, called Analytic Hierarchy Process-the Least Squares Distance Method (AHP-LSDM), for assessing a certain road traffic safety situation. This weights determination approach has a definite meaning in physics and combines the merits of both subjective and objective approaches.

(3) This paper uses the AHP-LSDM to determine the index weights of the index system for road traffic safety evaluation and thus provides theoretical foundation for the road traffic safety compositive evaluation method.

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