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Article

Comprehensive Assessment on Sustainable Development of Highway Transportation Capacity Based on Entropy Weight and TOPSIS

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Abstract: With the rapid development of the national economy of China, an increasing need for transportation facilities is becoming a serious challenge that the existing traffic system has to meet. Thus, the highway transportation capacity development level assessment has important significance in theory and in practice. In order to overcome the current defects of stronger subjectivity and experience in common assessment methods, the entropy weight and the TOPSIS method were introduced and employed to the comprehensive assessment of highway transportation capacity development. Shannon information entropy was applied to determine the weight value of each index in the comprehensive assessment model. After determining the index weight, the result of comprehensive assessment was obtained through the TOPSIS method. Finally, the effectiveness and feasibility of the proposed method were shown by application in practice.

Keywords: highway transportation capacity development; Shannon information entropy; TOPSIS; comprehensive assessment

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1. Introduction

With the rapid development of the national economy of China, an increasing need for transportation facilities is becoming a serious challenge that the existing traffic system has to meet. Thus, improving traffic capacity has become a vital way of solving traffic problems. Highway transportation plays an important role in today's economic and social life [1–4]. It greatly improves and enriches transportation capacity of passengers and cargo due to its strong capacity, high speed and flexible transportation mode [5]. Highway transportation development has a huge impact on economical and social development and becomes a basic condition of various kinds of industry development. Transportation occupies an extremely important position in economic and social development. It should be coordinated with the development of economic and social systems to achieve huge economic and social benefits [6–12]. At the same time, highway development is also needed intensively when the economy and society develop rapidly in China. A rapid, convenient, comfortable and sustainable transportation network needs to be established urgently alongside economic and social development. The development level shows a developmental status at a time and it reflects the development scale and degree of social economic phenomenon in each period. It is actually one of the specific values in the time series. Through the assessment of the development level of each period, we can know the sustainable development status in all periods and the trend of the development in future, which relates to the sustainability. However, highway transportation is still at a developmental stage in China and a complete and mature transportation system is not established. This will directly restrict the stable development of the Chinese economy and society. So, how best to plan and construct a highway transportation network and realize sustainable development of highway traffic becomes an urgent problem to solve. The comprehensive assessment of highway transportation development becomes an important basis, which evaluates the developmental the pros and cons of an existing highway transportation system. It is playing a vital role in highway transportation development [13]. Currently, many methods and models are applied in the comprehensive assessment of highway transportation development. However, most methods rely on stronger subjectivity and experiences in determining weight value. The objectivity and accuracy of weight value was unavoidably influenced. Thus, the comprehensive assessment results from different researchers are always full of uncertainty. Therefore, we have to find an effective comprehensive method for the assessment of highway transportation development, which has the characteristics of objectivity, simple operation and little interference.

Here, the entropy and the TOPSIS method were employed to the comprehensive assessment of highway transportation development. Shannon information entropy, which is an objective and applicable method for the determination of weight value, was introduced into the comprehensive assessment. It can calculate the weight value of each index more effectively in the comprehensive assessment of highway transportation development. In the application of the Shannon information entropy method, the greater entropy weight indicates a greater variation extent of the relevant index, enabling much more information and having a greater effect. So, the weight value of the corresponding index should also be bigger. In contrast, for the smaller entropy weight, which has little effect, its weight value should be smaller. One of the important contributions of our work is the combined use of entropy weight and TOPSIS, because using only one of these two techniques without the other might lead to unacceptable results.

The structure of this paper is as follows: we first briefly introduce the importance of highway transportation development assessment and clearly point out the advantages of the method employed. Then, the comprehensive assessment model of highway transportation development based on entropy and the TOPSIS method was introduced. In the following part, we focus on the application of the model in practice. Finally, through the application in highway transportation development assessment, the effectiveness and feasibility of the method are shown.

2. Entropy Weight Model

Entropy used to be a thermodynamic concept: it was introduced into information theory in 1948 by C. E. Shannon who put forward the concept of information entropy to measure the level of system chaos or disorder [14–19]. Shannon information entropy, which is an objective and applicable method for the determination of weight value, was introduced into the comprehensive assessment. In the application of the Shannon information entropy method, the greater entropy weight indicates greater variation extent of relevant index, which enables much more information and has a greater effect. So, the weight value of the corresponding index should also be bigger. In contrast, for the smaller entropy weight, which has little effect, its weight value should be smaller [17,18].

2.1. Data Standardization

Suppose the research plan is $x_{ij}\ (i=1,2,\cdots n; j=1,2,\cdots m)$. It denotes that there are i schemes and j indexes in the research plan. Based on appraisal target characteristics, the indexes are divided into the benefit type, the cost type and stationary indexes. The benefit type indexes are the indexes for which bigger values are better. The cost type indexes refer to the indexes for which smaller values are better. The stationary type indexes are the indexes whose values are constant.

For the benefit type indexes, the standardization is as follows:

$$y_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{1}$$

For the cost type indexes, the standardization is:

$$y_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{2}$$

where, $\max x_{ij}$ and $\min x_{ij}$ are the maximum and minimum value in index j respectively.

For the stationary factors, the standardization is:

$$y_{ij} = 1 - \frac{x_{ij} - x_{ij}^*}{\max\left|x_{ij} - x_{ij}^*\right|} \tag{3}$$

In the formula, x_{ij}^* is the best stable value in index j.

After the standardized processing, the standard matrix $y = (y_{ij})_{n\times m}$ can be obtained.

2.2. Determination of Entropy Weight

Suppose the weight vector of m targets is:

$$w = (w_1, w_2, \cdots, w_m), 0 \le w_j \le 1 \tag{4}$$

In order to determine weight values effectively, Shannon information entropy is introduced:

$$H = -\sum_{J=1}^{M} w_j \ln w_j \tag{5}$$

Through the formula of information entropy, it is possible to demonstrate that it is a double plan question. It should be transferred to a single objective mathematics model to make it easily calculable. Then, the established single objective mathematics model is as follows:

$$\min u\sum_{i=1}^{n} w_j(1-y_{ij}) + (1-u)\sum_{j=1}^{m} w_j \ln w_j \tag{6}$$

where, u is the equilibrium coefficient between two goals, and $0 < u < 1$.

Then the Lagrangian function was employed to solve this model. The Lagrangian function based on (5) is as follows:

$$L(w,\lambda) = u\sum_{i=1}^{n}\sum_{j=1}^{m} w_j(1-y_{ij}) + (1-u)\sum_{j=1}^{m} w_j \ln w_j - \lambda(\sum_{j=1}^{m} w_j - 1) \tag{7}$$

After solving (7) based on necessary conditions of existing extreme values, the weight model can be obtained:

$$w_j = \frac{\exp\{-[1+u\sum_{i=1}^{n}(1-y_{ij})/(1-u)]\}}{\sum_{j=1}^{m}\exp\{-[1+u\sum_{i=1}^{n}(1-y_{ij})/(1-u)]\}} \tag{8}$$

3. TOPSIS Model

The TOPSIS method (Technique for Order Preference by Similarity to an Ideal Solution) was first proposed by C.L. Hwang and K. Yoon in 1981. It is an ordering method based on the degree of closeness between limited appraisal objects and idealization objects, and it is a kind of relative advantages and disadvantages evaluation in the existing appraisal objects. It is also called the "advantages and disadvantages distance method". It is an effective method in multi-objective decision analysis [20–25]. Its basic principle is to order by calculating distance between appraisal objects and the optimal and worst solutions. If the appraisal objects are close to the optimal solutions, it keeps them away from the worst solutions, which is the best situation.

The ideal point and anti-ideal point are two basic concepts in the TOPSIS method. The ideal point is supposed as the optimal solution, all attribute values of which achieve the best value in all schemes. The anti-ideal point is supposed as the worst solution, all attribute values of which achieve the worst value [24,25].

Suppose d_i^+ is the distance between the scheme point and the ideal point, and d_i^- is the distance between the scheme point and anti-ideal point. According to the formula of Hamming distance, d_i^+ and d_i^- can be solved as follows:

$$d_i^+ = \sum_{j=1}^{m} w_j (y_{ij} - y_{+j})^{\frac{1}{2}} = \sum_{j=1}^{m} w_j (1 - y_{ij}) \tag{9}$$

$$d_i^- = \sum_{j=1}^{m} w_j (y_{ij} - y_{-j})^{\frac{1}{2}} = \sum_{j=1}^{m} w_j y_{ij} \tag{10}$$

where, y_{+j} is maximum value of index *j* among n assessment schemes and

$$y_{+j} = \max(y_{1j}, y_{2j}, \cdots, y_{nj}) \tag{11}$$

In contrast, y_{-y} is the minimal value of index *j* among n assessment schemes.

$$y_{-j} = \min(y_{1j}, y_{2j}, \cdots, y_{nj}) \tag{12}$$

In order to compare the distance between the scheme point and double base points, we can define:

$$T_i = d_i^+ / d_i^- \tag{13}$$

where, T_i is the relative quality level of the scheme i.

4. Application in Highway Transportation Development Assessment

The comprehensive assessment of highway transportation development becomes an important basis, which evaluates the pros and cons of existing highway transportation systems. It plays a vital role in highway transportation development. In order to show the possibility and effectiveness of the proposed method, the highway transportation development of Luoding City in recent years was viewed as an example. Then the comprehensive assessment model was employed in highway transportation development assessment [26]. Here, highway total mileage (X_1), the proportion of city township highway in total mileage (X_2), highway freight turnover (X_3), highway passenger turnover (X_4), motor vehicle population (X_5), highway traffic total investment (X_6), annual average quality rate of highway (X_7), annual daily traffic of national and provincial highway (X_8), and the rate of cement highway to administrative villages (X_9) were selected as the comprehensive assessment indexes according to the specific conditions of Luoding city traffic development. They are all related to sustainability of highway transportation development. The comprehensive assessment indexes of highway transportation development of Luoding City from 2006 to 2010 were shown in Table 1.

Table 1. Comprehensive assessment indexes of highway transportation development of Luoding City.

Assessment index	Years				
	2006	**2007**	**2008**	**2009**	**2010**
X_1 (km)	1353.3	1357.4	1360.2	1371.5	1854.12
X_2 (%)	83.2	83.2	83.3	83.4	87.7
X_3 (10k ton-km)	36,401	36,488	36,023	37,877	39,226
X_4 (10k passenger-km)	120,895	121,462	114,297	116,415	121,180
X_5 (veh)	5432	6218	6330	6502	9341
X_6 (ten thousand Yuan)	104,710	110,252	103,205	127,854	134,373
X_7 (%)	82.1	90.9	91.5	91.5	92.7
X_8 (veh per day)	39,248	29,855	29,465	31,056	33,891
X_9 (%)	95.8	100	100	100	100

veh: vehicles

The policy-making matrix is:

$$x_{5\times 9} = \begin{Bmatrix} 1,353.3 & 83.2 & 36,401 & 120,895 & 5,432 & 104,710 & 82.1 & 39,248 & 95.8 \\ 1,357.4 & 83.2 & 36,488 & 121,462 & 6,218 & 110,252 & 90.9 & 29,855 & 100 \\ 1,360.2 & 83.3 & 36,023 & 114,297 & 6,330 & 103,205 & 91.5 & 29,465 & 100 \\ 1,371.5 & 83.4 & 37,877 & 116,415 & 6,520 & 127,854 & 91.5 & 31,056 & 100 \\ 1,854.12 & 87.7 & 39,226 & 121,180 & 9,341 & 134,373 & 92.7 & 33,891 & 100 \end{Bmatrix}$$

Then, the standard matrix $y = (y_{ij})_{5\times 9}$ can be obtained based on policy-making matrix:

$$y_{5\times 9} = \begin{Bmatrix} 0 & 0 & 0.1180 & 0.9209 & 0 & 0.0483 & 0 & 1 & 0 \\ 0.0082 & 0 & 0.1452 & 1 & 0.2011 & 0.2261 & 0.8302 & 0.0399 & 1 \\ 0.0134 & 0.0222 & 0 & 0 & 0.2297 & 0 & 0.8868 & 0 & 1 \\ 0.0363 & 0.0444 & 0.5788 & 0.2956 & 0.2783 & 0.7908 & 0.8868 & 0.1626 & 1 \\ 1 & 1 & 1 & 0.9606 & 1 & 1 & 1 & 0.4524 & 1 \end{Bmatrix}$$

Here, suppose $u = 0.5$, according to the formula (8), the weight vector of m targets can be obtained. The weight value of each index is shown in Table 2.

Table 2. Weight value of each index.

Assessment index	Weight value
X_1	0.0196
X_2	0.0199
X_3	0.0431
X_4	0.1641
X_5	0.0379
X_6	0.0539
X_7	0.2517
X_8	0.0359
X_9	0.3739

Then, based on the TOPSIS model, the distances between scheme point and double base points can be determined. Relative quality level of the scheme i T_i was shown in Table 3.

Table 3. Relative quality level.

T_i	Value
T_1	4.1361
T_2	0.2910
T_3	0.6488
T_4	0.3676
T_5	0.0268

We can obtain the result of comprehensive assessment of highway transportation development of Luoding City according to the table above. The result of comprehensive assessment was shown in Table 4.

Table 4. Result of comprehensive assessment.

Years	Order of development level
2006	5th
2007	2nd
2008	4th
2009	3rd
2010	1st

From Table 4, we can know the highway transportation development conditions of Luoding City in recent years. From 2006 to 2008, the highway transportation development level gradually increased. However, the highway transportation development was lower than the previous year. It simply reflected the actual development situation and conformed the development environment at that time. Since 2009, the highway transportation development level has gradually increased. Moreover, the development level is relatively high. Here, the results of highway transportation development assessment we obtained were in accordance with the results of [21]. The effectiveness and feasibility of the proposed method were shown.

5. Conclusions

The comprehensive assessment of highway transportation development level has important significance in theory and practice. It is also an important basic for realizing the status of highway transportation capacity development. Here, entropy and the TOPSIS method were employed to evaluate objectively and effectively the status of highway transportation capacity development. From the analysis of the assessment indexes, we know that the highway passenger turnover, annual average quality rate of highway, and the rate of cement highway to administrative villages are the three primary factors with higher weight coefficient. Moreover, more attention should be paid to them in future highway traffic development. From the final comprehensive assessment result obtained, we can also assess the highway traffic development status and trend of Luoding city in recent years. The results show that highway traffic of Luoding city has an improved development status. Moreover, with the rapid development of the economy and the increasing investment in highway construction, we can anticipate further positive development in the future. This assessment method can control and guide the development of the highway transportation capacity further. The comprehensive assessment results are acceptable and they showed the effectiveness and feasibility of the method proposed. The study provides an effective method for the assessment of highway transportation development level and the related fields.

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Author Contributions

Yancang Li designed research; Lei zhao performed research and analyzed the data; Juanjuan Suo wrote the paper. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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