Comprehensive Assessment of Green Development Level for Urban Rail Transit Enterprises Based on ANP and Entropy Weight Method

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Abstract. As one of the most efficient energy-saving transportation modes, urban rail transit system, with priorities such as large volume, low pollution, low-emission transport mode, has been greatly developed in many Chinese cities recently. In order to evaluate the current green development level (GDL) and guide the future green development for urban rail transit enterprise (URTE), a comprehensive evaluation approach is proposed. First, based on the analysis of connotation and basic characteristics of green URTE, an assessment indicator system considering the impact of energy-intensity, level of service, energy-saving capacity building, application of energy-saving technologies, energy-saving management mechanism, fund input level for energy-saving is established. Second, the analytic network process (ANP) and the entropy weight method are used to respectively determine the subjective and objective weights, and the game theory aggregation method is employed to combine both weights and then optimize the indicator weigh. Finally, based on the investigation data, the GDL values of several Chinese URTEs are analysed and compared. The results show that the proposed method has both well rationality and excellent operation performance. The weight determination method effectively solve the collaborative relationship between different methods and the GDL calculation can well identify the URTEs' benefits and drawbacks to promote UTREs pertinently carrying out energy saving measures.

1. Introduction
Under the background of global warming, the international community generally agrees that the development of green and low-carbon transport is an effective measure for sustainable economic development (1). Hence, it’s necessary to establish a scientific and reasonable comprehensive assessment method to evaluate the GDL of urban rail transit enterprise (URTE) which can comprehensively reflect the characteristics and factors of energy consumption and emphatically analyze the importance of the multiple indicators which affect GDL of enterprise realizing the goal to lead the enterprise develop sustainably, and promote the development of energy conservation work of the transportation industry.

At present, the energy conservation evaluation of urban rail is to establish energy performance indicators. The rigorous attempt to identify energy performance indicators in railway systems has been developed within the Rail Energy project (2; 3). This approach consisted of seven indicators measuring the overall energy consumption of the system, the energy consumption share for parked trains, the rate of recuperated energy and the efficiency of the railway distribution grid. González-Gil et al. (4) proposed a holistic approach which considers the numerous interdependences between
subsystems, such an approach requires a comprehensive set of energy consumption-related Key Performance Indicators (KEPIs). In China, Chinese Urban Rail Transit Association published data to monitor some indicators data in Urban Rail Transit annual statistical and analytical report (5;6). However, annual data only can reflect the basic situation of urban rail transit enterprises, but failed to develop a unified standard metering energy consumption statistics. But it only can see the energy consumption results of enterprises without considering the energy conservation capacity-building. Additionally, in the field of green evaluation of transportation enterprises, Ministry of Transport of the People’s Republic of China (MOT) has studied the assessment indicator system of the Low Carbon Transport System, green highway passenger transportation enterprise and green shipping enterprise, etc. (7). Thus, for making up the blank of green URTE assessment, it’s necessary to establish a comprehensive evaluation method of green URTE.

In the study of classical comprehensive evaluation, the commonly used methods to determine the indicator weight are divided into subjective and objective method. Subjective method is mainly based on the research purpose and indicator connotation to analyze subjectively and make judgement to determine the relative importance of the various indicators, such as the analytic hierarchy process(AHP) method proposed by Professor Saaty and other method applied in the literature (8;9). Using subjective method to determine indicator weight can reflect the actual importance of the different indicators by consulting experts, but such indicator weight has different degrees of dependence on the experts. Instead, objective method can avoid the human factors and subjective factors by using mathematical calculation. It’s viewed that this method can fully reflect the differences between the data by calculations based on relationships between objective evaluation data, which also has shortcomings that can’t reflect the real importance of various indicators. Therefore, this paper determined the subjective and objective of indicators based on analytic network process (ANP) and entropy weight theory, and used game theory aggregation method to seek equilibrium results of the two methods to obtain comprehensive weights and apply the investigation data to expand the evaluation analysis of green URTE.

2. Green URTE assessment indicator system

In order to ensure the rationality of assessment indicator system constructed, researchers extensively investigated the status of energy conservation of several urban rail transit enterprises such as Beijing, Wuhan, and Chengdu. Additionally, researchers surveyed the evaluation indicator adaptability including the representativeness, information or data accessibility of indicators to understand the indicator collection difficult degree. At the same time, the experts from relevant departments of enterprise, energy consumption field, and industry regulation department were repeatedly consulted to revise the indicator system. Finally, the evaluation system of green URTE was determined as follows.

| Table 1. Assessment indicator system of green URTE |
|---------------------------------|
| **Objective** | **Indicator in level one** | **Indicator in level two** |
| GDL of URTE | energy-intensity \( c_i \) | Traction power consumption per vehicle-kilometer \( e_{i_1} \) |
| |  | Traction power consumption per person-kilometer \( e_{i_2} \) |
| |  | Station power consumption unit area per day \( e_{i_3} \) |
| |  | Non-operating comprehensive energy consumption unit area per day \( e_{i_4} \) |
| |  | Year on year (YoY) decline of Traction power consumption per vehicle-kilometer \( e_{i_5} \) |
| |  | YoY decline of traction power Consumption per person-kilometer \( e_{i_6} \) |
| |  | YoY decline of station power consumption unit area per day \( e_{i_7} \) |
### Table
| Category                          | Subcategory                                                                 |
|----------------------------------|-----------------------------------------------------------------------------|
| YoY decline of Non-operating comprehensive energy consumption unit area per day | YoY decline of Non-operating comprehensive energy consumption unit area per day ($e_{31}$) |
| Average load factor              | ($e_{32}$)                                                                  |
| Average load factor of peak hour | ($e_{33}$)                                                                  |
| Average train interval           | ($e_{34}$)                                                                  |
| Average speed                    | ($e_{35}$)                                                                  |
| Line configure rate setting      | Line configure rate setting platform screen doors ($e_{36}$)               |
| Comfortable degree of air-conditioning | Comfortable degree of air-conditioning ($e_{37}$)                      |
| Air conditioning usage rate      | ($e_{38}$)                                                                  |
| Configuration rate of standard   | Configuration rate of standard elevator and escalator units entrances      |
| elevator and escalator units     | accounted for subway operation time ($e_{39}$)                            |
| Application of intelligent       | Application of intelligent dispatching or auxiliary operations management    |
| dispatching or auxiliary          | and decision-making system ($e_{40}$)                                      |
| technology                       |                                                                             |
| Energy-saving vehicle            | Configuration rate of energy-saving vehicle ($e_{41}$)                     |
| Circumstance of using energy-saving technologies, | Circumstance of using energy-saving technologies, equipment ($e_{42}$)      |
| Energy conservation-related     | Energy conservation-related awards, honors, patented products, etc. ($e_{43}$) |
| awards, honors, patented          |                                                                             |
| products, etc.                   |                                                                             |
| Energy-saving organizations      | Energy-saving organizations ($e_{44}$)                                     |
| Energy-saving regulations        | Energy-saving regulations ($e_{45}$)                                       |
| Energy management measures       | Energy management measures ($e_{46}$)                                      |
| Energy publicity and training    | Energy publicity and training ($e_{47}$)                                   |
| Energy-saving independent input  | Energy-saving independent input rate ($e_{48}$)                            |
| rate                             |                                                                             |
| Energy-saving subsidies input    | Energy-saving subsidies input rate ($e_{49}$)                              |
| rate                             |                                                                             |

### 3. Methodology

#### 3.1. Subjective weights calibration based on ANP

ANP is a more realistic and practical decision-making method which derives from the AHP method to adapt interrelated hierarchical structure. The steps to determine the subjective weights are as follows.

1) Establish green URTE network hierarchy structure based on ANP. By analyzing the dependence and feedback relationship between elements, the interaction between elements is obtained to build the ANP network hierarchy structure of green URTE.

2) Construct the judgment matrix $W_{(p,r)}$. Set $p_1, L, r, p_n$ as the elements of control layer, under the control layer, there are some element groups $C_1, L, C_N$ of the network layer, which has elements $e_{i1}, L, e_{in}, i = 1, L, N$ in element group $C_i$. 

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3) Calculate super matrix $W$. Super matrix is consisted of many submatrices. The ranking vector $(w_{ni}, L, w_{ni})$ of judgment matrix $W_{(n,r,j)}$ can be obtained based on eigenvalue method.

4) Construct weighted super matrix and limit matrix. By taking $P_s$ as criteria, compare the importance of each group of elements under $P_s$ to the criteria $C_j (j=1, L, N)$, and get the weighting matrix $A$ by the eigenvalue method. The subjective weights $W_i$ based ANP can be obtained by the limit relative ranking vector.

3.2 Objective weights calibration based on entropy weight
The basic principle of entropy weight method is based on the variability size of indicator to determine the objective weights. Thus, this indicator plays a more important role in the comprehensive evaluation and the weight is also correspondingly larger. The steps to determine the objective weights are as follows.

1) Construct decision matrix $X$. Assume there are $m$ evaluation objects and $n$ evaluation indicators. According to the characteristic values of each indicator in the indicator system, decision matrix with the element $x_{ij}$ is built, which is expressed as the form of $X = (x_{ij})_{m,n}$.

2) Standardization of decision matrix. For positive indicator, the standardized value $r_{ij}$ of $x_{ij}$ is shown as Eq. (1). And for negative indicator, the standardized value $r_{ij}$ of $x_{ij}$ is shown as Eq. (2):

$$ r_{ij} = (x_{ij} - \min(x_{ij}))/ (\max(x_{ij}) - \min(x_{ij})) \quad (1) $$
$$ r_{ij} = (\max(x_{ij}) - x_{ij})/ (\max(x_{ij}) - \min(x_{ij})) \quad (2) $$

3) Determine the entropy and entropy weight of indicator. Make $p_{ij} = r_{ij}/ \sum_{j=1}^{n} r_{ij}$, and the entropy $H_j$ of $j$-th indicator is Eq. (3):

$$ H_j = -(1/\ln m) \sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad (3) $$

4) Thereby, the objective weights of indicators $W_j$ are obtained based on entropy weight method.

3.3 Weights optimization based on game theory
The subjective and objective weights of indicators are obtained by using ANP and Entropy weight method which are respectively expressed as $W_1$ and $W_2$. For taking into account the actual importance and objective truth, and seek agreement or compromise between the subjective and objective weights, the game theory is used to minimize each deviation between the possible comprehensive weights and each basic weights. Remember any linear combination of the two weight vectors $W_1$ and $W_2$ as Eq. (4):

$$ W = \sum_{k=1}^{3} \alpha_k W_k^T \quad (4) $$

Where $W$ is the comprehensive weight, $\alpha_k$ is the weight coefficient of $k$-th weight determination method, $W_k$ is the weight vector of $k$-th weight determination method.

The optimization objective is as Eq. (5):

$$ \min \left\| \sum_{k=1}^{3} \alpha_k W_k^T - W_i^T \right\|_l = 1, 2 \quad (5) $$
According to differential properties of matrix equation, the optimized first derivative condition of the Eq. (2) is 
\[ \sum_{k=1}^{2} \alpha_k \cdot W_k \cdot W_k^T = W_l \cdot W_l^T, l = 1,2. \] 
And the corresponding linear equations is as Eq. (6):

\[
\begin{pmatrix}
W_1 \cdot W_1^T & W_1 \cdot W_2^T \\
W_2 \cdot W_1^T & W_2 \cdot W_2^T
\end{pmatrix}
\begin{pmatrix}
\alpha_1 \\
\alpha_2
\end{pmatrix} =
\begin{pmatrix}
W_1 \cdot W_1^T \\
W_2 \cdot W_2^T
\end{pmatrix}
\]  

(6)

According to the Eq. (6), the optimal solution \( \alpha_1 \) and \( \alpha_2 \) can be obtained and then the comprehensive weight \( W \) can be got by substituting \( \alpha_1 \) and \( \alpha_2 \) into the Eq. (4).

4. Case study

4.1. Indicator weight evaluation

By using the investigation data obtained from department heads of urban rail transit enterprises, experts and scholars in the field of energy consumption, the industry regulation organization etc., and researchers determined the subjective, objective and comprehensive weights values based on the three above methods, and also analysed the evaluation results. A radar chart about subjective, objective and optimized weight of indicators was drawled. In Figure 1, each axis indicates the weight value of the evaluation indicator, and the weight value increased accordingly with dotted line extending from the inner to the outside.

![Radar chart of evaluation indicator weight](image)

Figure 1. Radar chart of evaluation indicator weight

Figure 1 shows that the optimized weight basically covered closed region of the subjective and objective weights, indicating that the optimized weight can reflect the information provided by real data, but also objectively reflect the importance degree of each indicator, which avoid the defect of subjective and objective weight. Meanwhile, the weight of indicator \( e_{33} \) to \( e_{34} \) was relatively high, indicating that the indicators of the three elements energy-saving capacity building, application of energy-saving technology, and energy-saving management mechanism had great impact on the level of green development of urban rail transit enterprise.

In summary, while promoting the green development of urban rail transit enterprise, enterprise should strengthen the energy-saving capacity building, application of technology and improvement of management level, and raise awareness of energy saving autonomous. At the same time, energy-intensity and level of service also should be concerned.

4.2. Analyses of evaluation result

During evaluating the GDL of urban rail transit enterprise, the indicator standardization eigenvalues of each evaluation object are weighted by the optimized weight of each indicator and then were added up
to obtain the comprehensive indicator values of green development. As shown in Table 2, on the whole, the most advanced enterprise is A, followed by B, C, D. From the specific indicators, the majority of indicators in level two of the elements energy-saving capacity building, application of energy-saving technologies, energy-saving management mechanism, fund input level for energy-saving are more excellent than other enterprises, indicating that enterprise input higher in the energy-saving to promote green and sustainable development. But it should be noted while strengthening energy-saving construction, enterprise also should take into account of passenger sensory experiences and appropriately improve service quality.

Thus, for an earlier construction enterprise, if it’s possible, it should appropriately improve the service level. For the late construction enterprises, improving the awareness of energy conservation and strengthening capacity construction and energy-saving management is the necessary work for them to carry out.

| Table 2. Green Development Comprehensive Indicator Values |
|----------------------------------------------------------|
| **Indicator value**                                      | **Urban rail transit enterprises** |
|                                                          | A  | B  | C  | D  |
| energy-intensity                                        | 0.104 | 0.067 | 0.118 | 0.087 |
| level of service                                        | 1   | 6  | 7  | 8  |
| energy-saving capacity building                         | 0.121 | 0.136 | 0.129 | 0.136 |
| application of energy-saving technologies               | 2   | 4  | 1  | 4  |
| energy-saving management mechanism                      | 0.172 | 0.104 | 0.076 | 0.036 |
| fund input level for energy-saving                      | 9   | 4  | 0  | 0  |
| GDL (comprehensive indicator)                           | 0.124 | 0.129 | 0.069 | 0.049 |
|                                                          | 4   | 0  | 4  | 3  |
| GDL (comprehensive indicator)                           | 0.175 | 0.116 | 0.058 | 0.000 |
|                                                          | 0   | 6  | 3  | 0  |
| GDL (comprehensive indicator)                           | 0.055 | 0.056 | 0.019 | 0.000 |
|                                                          | 3   | 4  | 3  | 0  |
| GDL (comprehensive indicator)                           | 0.752 | 0.610 | 0.470 | 0.3096 |

5. Conclusions

This paper first established an assessment indicator system for green URTE based on analysis of connotation and the basic characteristics of green URTE. The assessment indicator system proposed can comprehensively reflect the GDL of URTEs from six aspects including energy-intensity, level of service, energy-saving capacity building, application of energy-saving technologies, energy-saving management mechanism, fund input level for energy-saving.

In addition, to ensure the accuracy of evaluation results, three methods were used to determine the indicator weight. The subjective and objective weights were determined using ANP and entropy weight method, and then, game theory method was used to combine the subjective and objective weights which not only overcome the AHP and single entropy method to determine indicator weights deviating from the actual situation, but also optimize the weight of through game theory to seek consensus or compromise between the objective and subjective weight. This method takes into account of both the actual importance of indicators and the authenticity of objective data. Furthermore, the GDL evaluation results of four Chinese URTEs are consistent with the actual data acquired and GDL calculation also can identify the URTEs’ benefits and drawbacks which indicate the proposed method has both well rationality and excellent operation performance.

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